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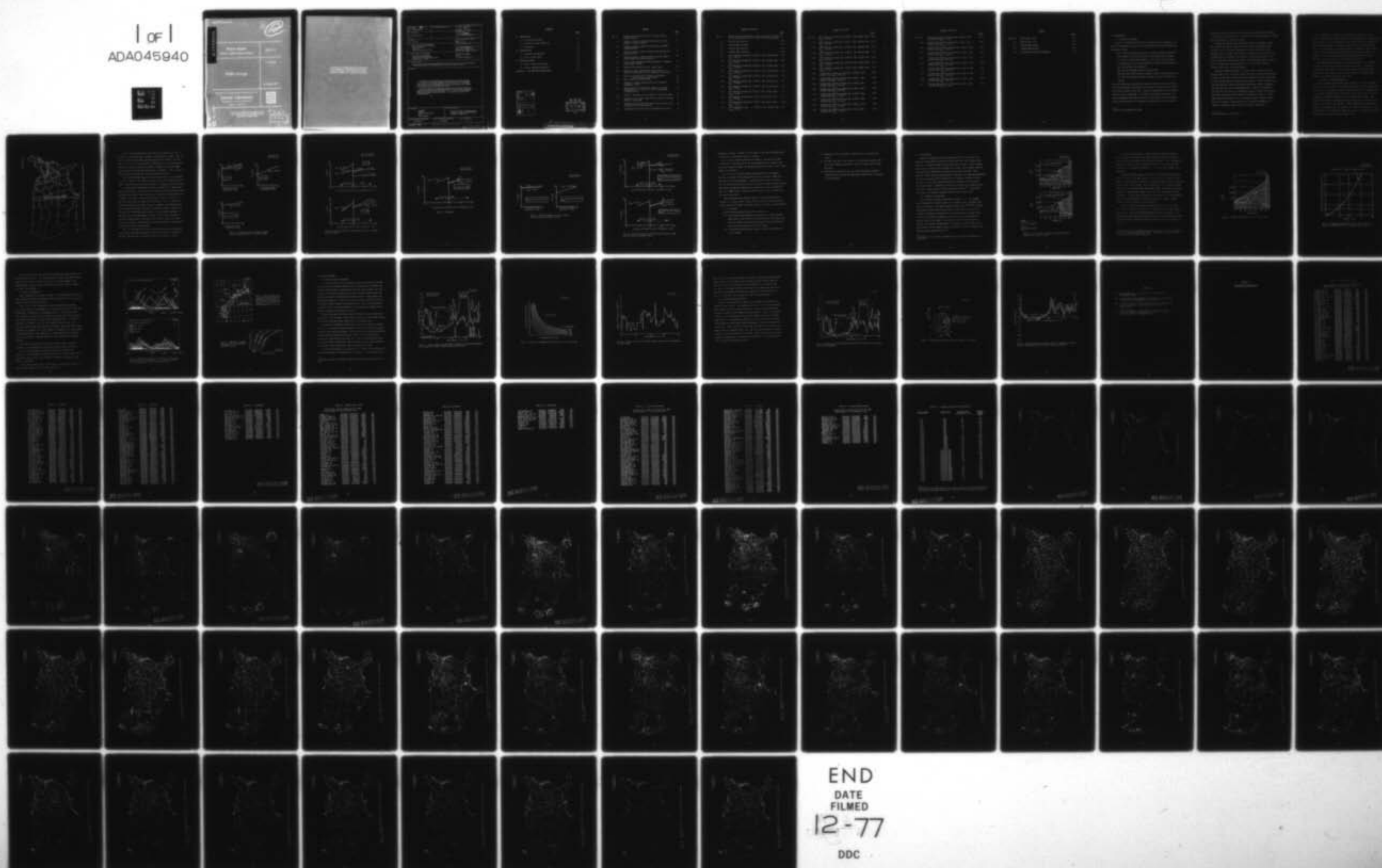

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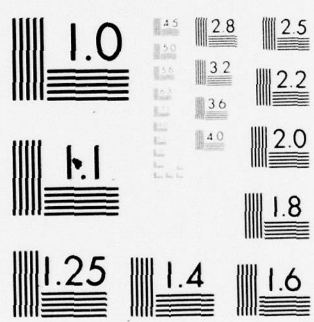

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

Report No. FAA-RD-77-77

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Project Report

Discrete Address Beacon System

ATC-75

S. I. Krich

DABS Coverage

16 August 1977

Prepared for the Federal Aviation Administration by

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LEXINGTON, MASSACHUSETTS

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16. Abstract

DABS sensors are to be installed at FAA ASR and ARSR sites throughout continental U.S. as a part of the evolutionary upgrading of the third generation ATC Radar Beacon System (ATCRBS). It is therefore important to establish: (1) the degree of 3D coverage which would be provided by such deployment; and (2) a reasonable balance between number of installations, sensor maximum range, and coverage.

This paper reports on a coverage study in which DABS coverage within CONUS was projected on a statistical or "percent coverage" basis by purely geometrical considerations. Results are given for CONUS, the eastern half of the U.S., and for the Golden Triangle. Profile coverage ("line-of-sight coverage down to ....") is given for the Boston-NYC-Washington corridor.

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1.0 INTRODUCTION

1.1 Motivation and Method

Results of a CONUS-scale surveillance coverage study are presented. The study was motivated by a need to better understand the trade-offs behind such questions as these:

- Will a network of DABS beacon sensors located at present and proposed ASR and ARSR sites provide surveillance and communication coverage of all major airlanes within CONUS? - if so, down to what altitude?
- Are DABS sensors at every ASR and ARSR site planned really necessary?; what fraction might be eliminated?
- What free space maximum range must DABS provide?
- Will ARSR long range sensors be essential should surveillance data from ASR type radars eventually become available to other facilities via a network?

Coverage patterns were calculated for sensors located at each of the 146 ASR sites and 94 ARSR sites existing in 1974 and those 117 ASR sites and 21 ARSR sites being proposed at that time*. These were superimposed to form composite, national-scale, coverage maps. All coverage calculations were made by the DOD Electromagnetic Compatibility Analysis Center (ECAC), based upon computer stored representations of the topography surrounding each site. Topography

*Proposed sites identified by ECAC.

data were provided by ECAC and sensor characteristics and specific altitudes of interest by Lincoln Laboratory. Analysis of the resulting composite coverage maps was performed at Lincoln Laboratory.

Coverage for a given sensor was defined simply as the region of space that could be seen without terrain obstruction up to some maximum range. Coverage at a given altitude represents a horizontal slice through this coverage volume. Coverage, thus obtained, is usually circular in shape with circumferential scalloping in the direction of interferring terrain. Constant altitude above mean sea level (MSL), rather than above sensor or ground level, was used since aircraft generally fly at a specified "above MSL altitude" based upon a pressure altimeter.

The method employed by ECAC* to calculate sensor coverage for given maximum range cut-off, and given altitude takes into account terrain features, but does not take into account the effects of obstructions such as buildings or other man-made objects visible along the horizon. In some locations, e.g., the Boston ASR site, airport and skyline obstructions reduce coverage much more than the hills of the surrounding terrain. Thus it was necessary to partially take the effects of obstructions along the horizon into account by arbitrarily setting the sensor elevation coverage lower limit to a small angle above the horizontal (i.e., by setting the sensor elevation cut-off angle at 1/4 degree). Refractivity due to the earth's atmosphere was handled by assuming an earth of radius 1/3 greater than actual.

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*See References [2], [3] and [4].

It is important to recognize the limitations of this model. First, Section 2 shows that the terrain model used is not applicable to a low altitude coverage study; i.e., MSL altitude where some terrain features are above the altitude being considered. Secondly, for many sensor locations, buildings have a far greater affect upon coverage than does topography. This is more of a problem for the ASRs located on the airport surface than the ARSRs. An example of this is the Boston ASR where building obstructions far exceed that due to terrain or the $1/4^{o}$ cut-off angle; see Section 3.

The assumed model, along with a sensor maximum range cut-off, resulted in most coverage patterns at high altitudes being circles. In retrospect, a model which simply draws circles of coverage around each site where the radius of the circle depends upon the sensor altitude, and maximum range would have been nearly as good for this study.

1.2 Composite Coverage Summarized

Percent coverage statistics have been computed for the Golden Triangle (Boston - Chicage - Atlanta), the Eastern United States, and the entire CONUS (see Fig. 1.1). By percent coverage is meant the percent of a geographic area at a given MSL altitude that can be seen by at least one sensor. The Golden Triangle was considered separately due to the high traffic volume. The Eastern United States, including the Golden Triangle, was considered only for 5000 ft. and 10,000 ft. MSL altitudes. CONUS, including the Eastern United States, was considered only for altitudes of 10,000 ft. MSL and above. Lower altitudes were not considered for CONUS since much of the ground in the Western United States is between 5,000 and 10,000 ft. MSL.

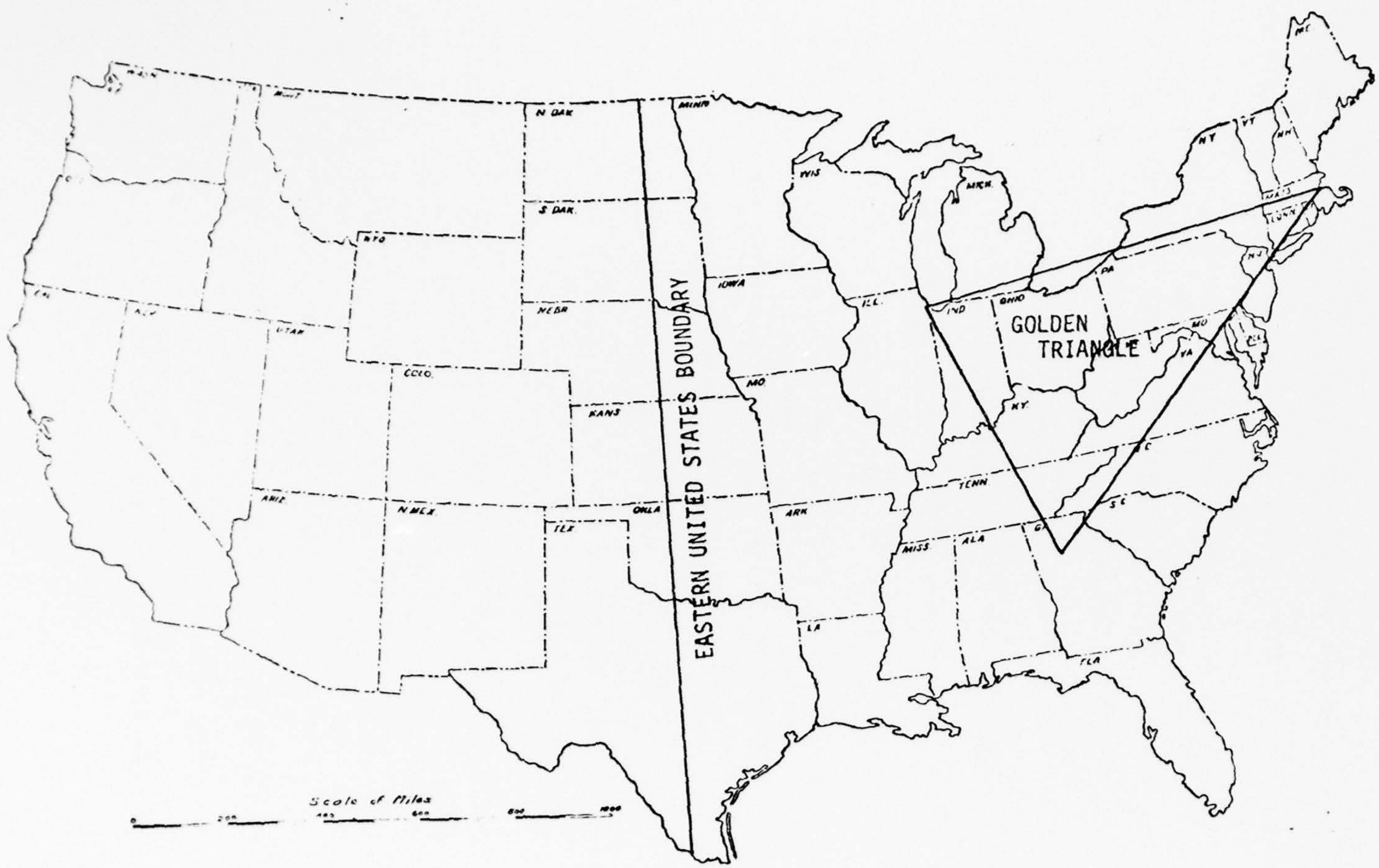


Fig.1.1. Eastern United States and Golden Triangle (Boston-Chicago-Atlanta).

Percent coverage predicted by these models are summarized in Figs. 1.2 through 1.5 for various sensor deployments and geographic regions. Figs. 1.2 and 1.3 describe ASR and ARSR coverage separately and combined. The left hand side of Fig. 1.3, below 10,000 ft., summarizes only the Eastern United States; the right hand side above 10,000 ft. summarizes the entire CONUS. This accounts for the coverage discontinuity at 10,000 ft. Figs. 1.4 and 1.5 repeat the study combining the present and proposed sensors.

Sensor maximum ranges (R_{max}) of 60, 100 and 150 nmi are also considered in Figs. 1.2 and 1.5. Due to earth curvature and the sensor model no additional coverage would be provided at 10,000 ft. for R_{max} greater than 105 nmi.

A concept under consideration includes the netting of all DABS sensors within a given region. This will tend to remove the distinction between ASRs and ARSRs since enroute centers may very well receive surveillance data from a network of ASR sites. For good low altitude coverage, a sensor on or near the airport would be required at many airports. Fig. 1.2 shows that excellent coverage of the Golden Triangle is supplied by the ASRs and that little additional coverage is gained by including the ARSRs. Therefore in this region the ARSRs would not be needed in a netted DABS deployment. In addition, due to the large number of sensors in this region, increasing the sensor maximum range to 100 nmi instead of 60 nmi yields only a small increase in coverage. The increased range may be desirable to provide back-up coverage in case of sensor outage.

Fig. 1.3 also shows that in the Eastern United States, the ARSRs would provide little additional coverage over what would already be provided by the ASRs, and thus many of the ASRS's would not be needed in a netted

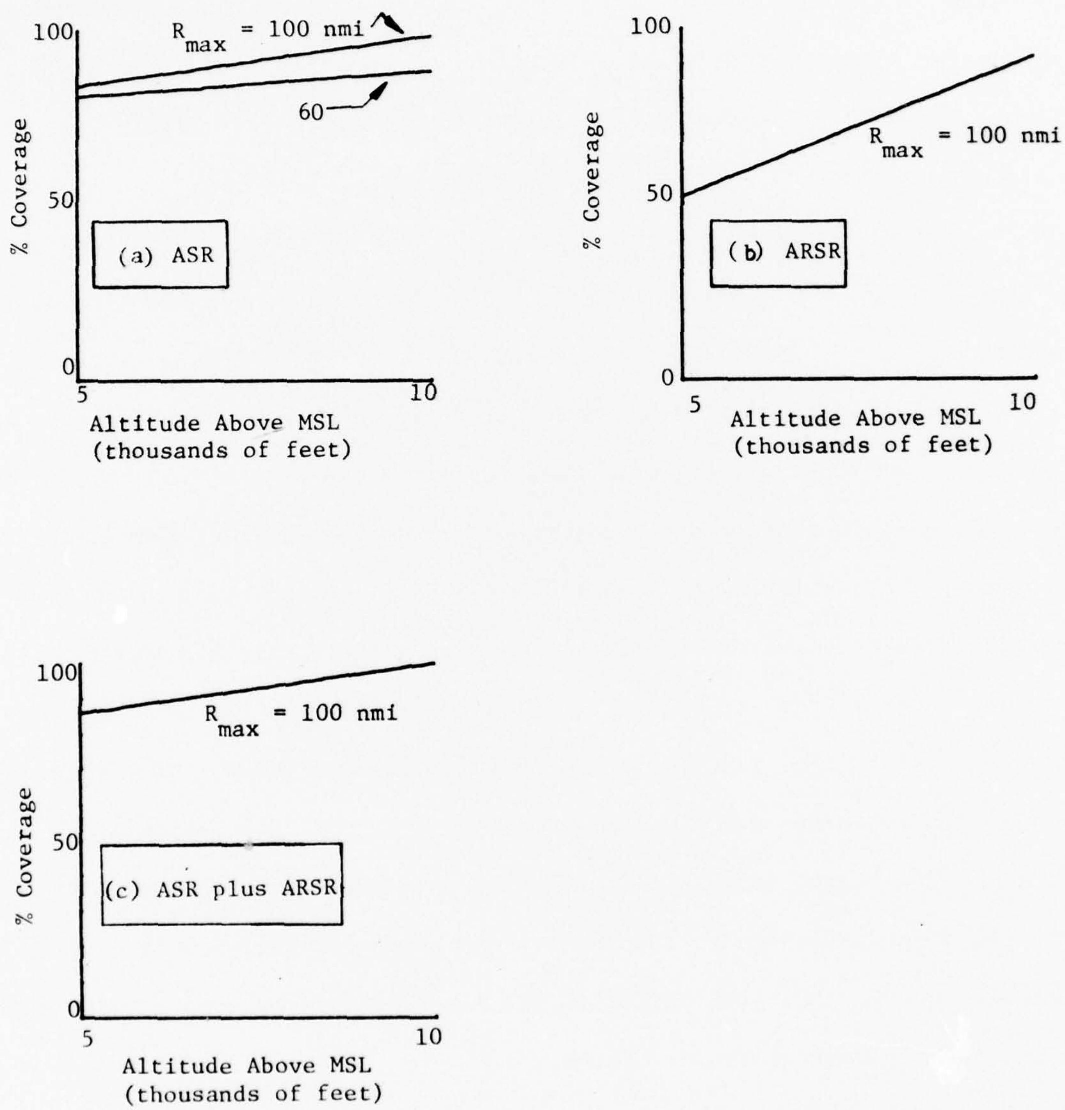


Fig.1.2. Percent coverage in Golden Triangle (Boston-Chicago-Atlanta) — existing sensors.

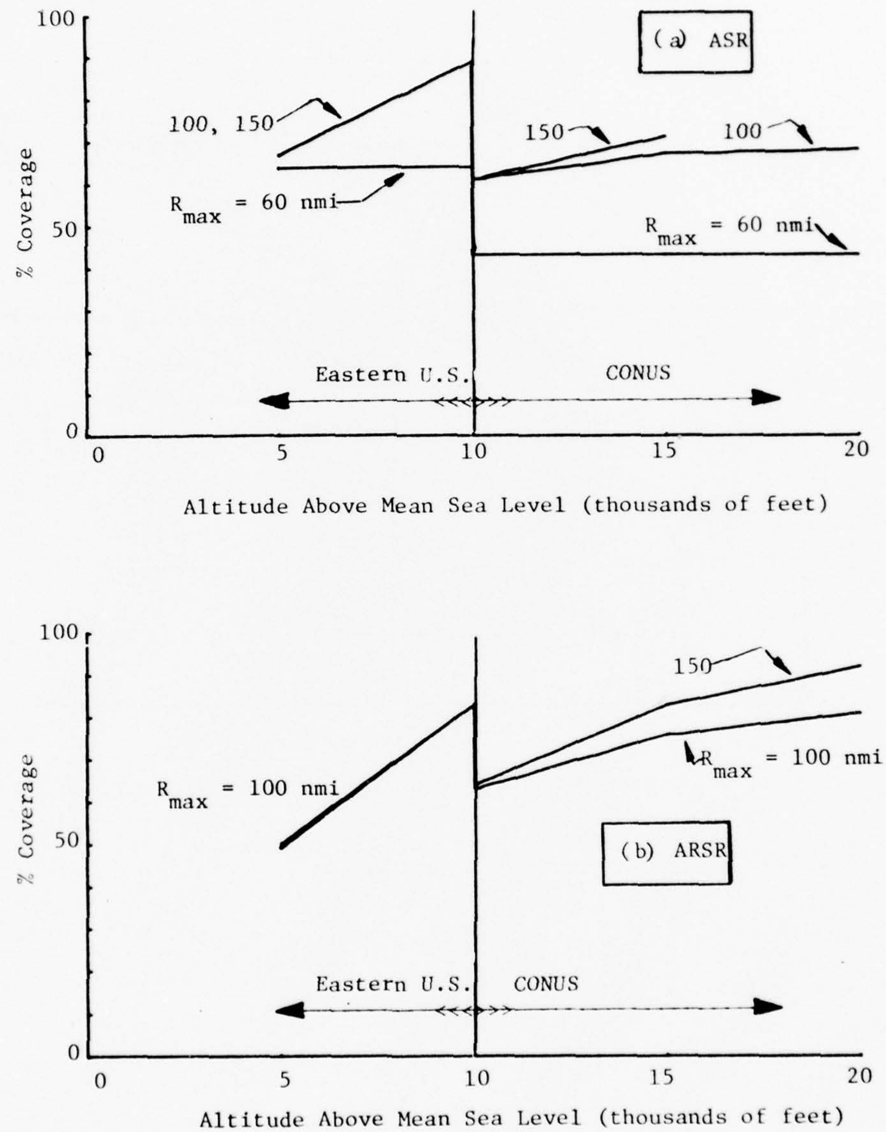


Fig.1.3. Percent coverage in Eastern United States and CONUS — existing sensors.

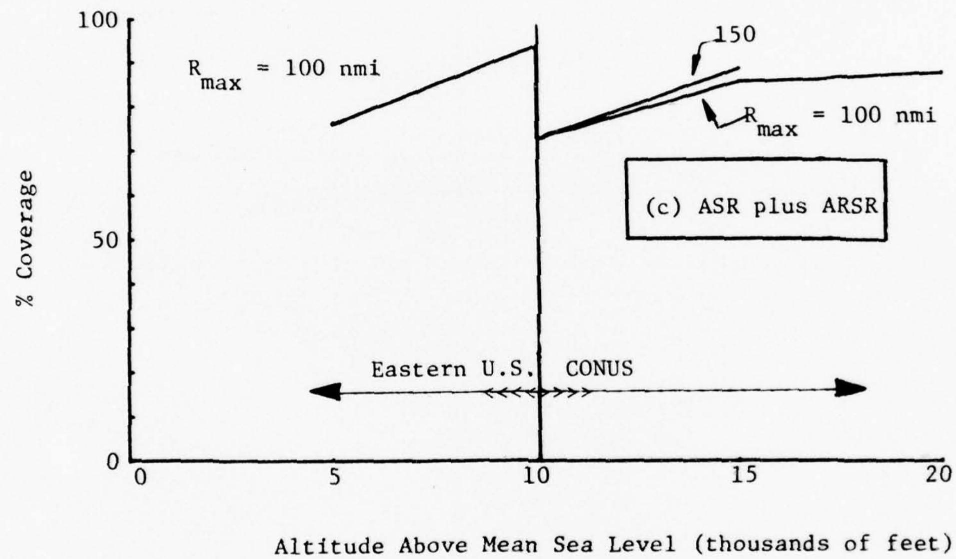


Fig.1.3. Continued.

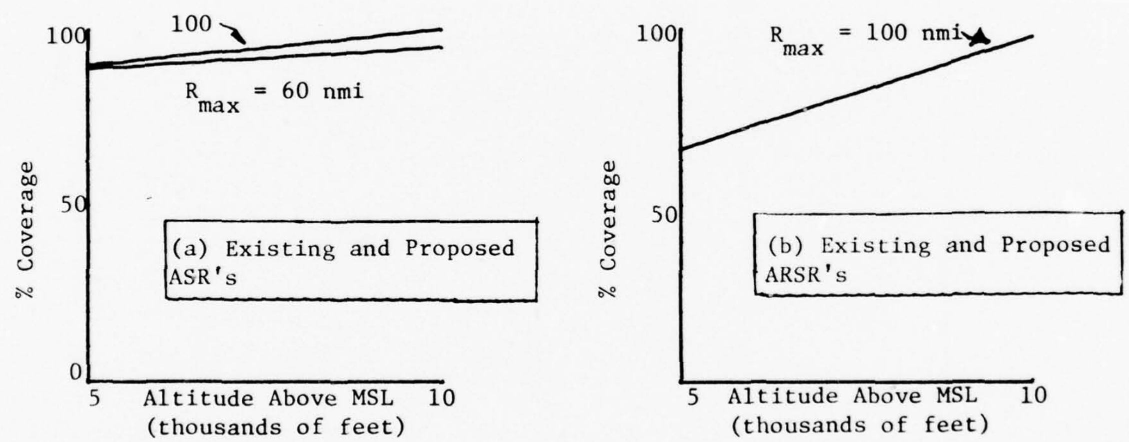
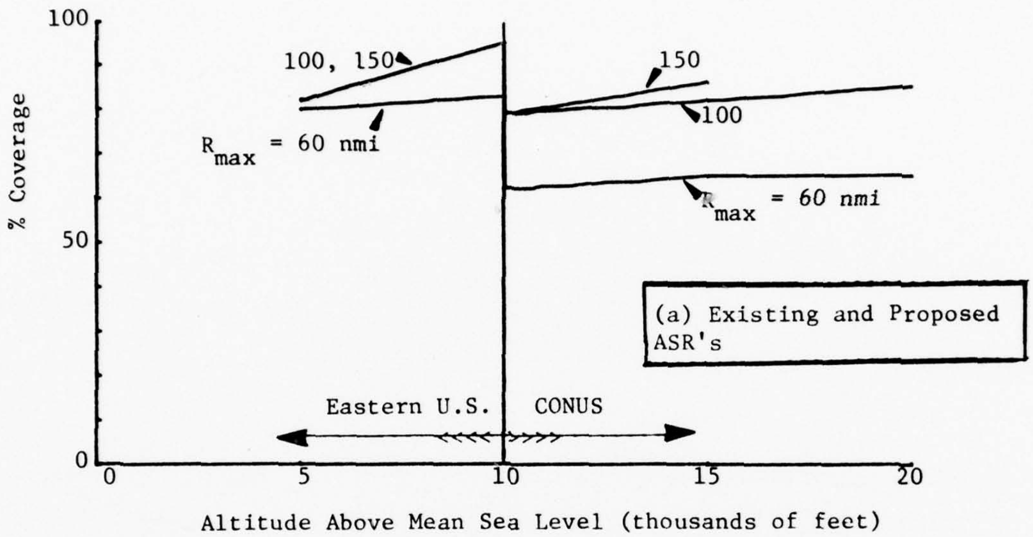


Fig.1.4. Percent coverage in Golden Triangle from existing and proposed sensors.



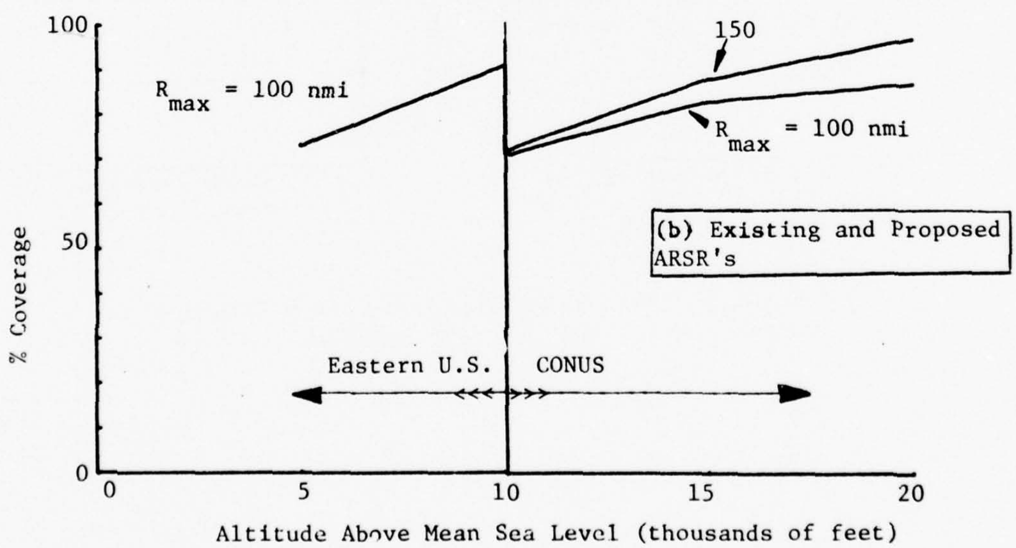


Fig.1.5. Percent coverage in Eastern United States and CONUS from existing and proposed sensors.

deployment of sensors. However, in this region, increasing the maximum range to 100 nmi has a significant effect on coverage.

Fig. 1.3 also considers altitudes of 10,000 ft. and above over CONUS. It shows that in the West many of the existing ARSRs will be needed to fill in the gaps between the ASRs. The missing regions can be filled in with a small number of new sensors.

Figs. 1.4 and 1.5 show the percent coverage where the 117 proposed ASRs have been added to the existing ASR's and the 21 proposed ARSRs have been added to the existing ARSRs. A comparison between Figs. 1.2 and 1.4 for the Golden Triangle shows that little increase is gained with the proposed ASRs added; coverage above 5000 feet was already good. The extra ARSRs do help. On a CONUS basis, a comparison between Figs. 1.3 and 1.5 shows that the extra sensors help.

Results presented here should be viewed as a rough approximation to coverage on a national scale. Sensor location selection requires detailed on-site analysis and should not be made solely on the basis of terrain models.

1.3 Conclusions

Broad conclusions which follow from the study are:

(1) In the Eastern United States and especially the Golden Triangle, DABS sensors at the ASR sites would provide good surveillance data for both terminal and en-route Air Traffic Control with netting. Sensors at most ARSR sites will not be needed.

(2) In the Western United States, sensors at many of the ARSR sites will be needed.

(3) Buildings can be a far greater limiting factor on coverage than terrain.

(4) The model used here is not valid for a low altitude coverage study and is only slightly better than a smooth 4/3 earth model at high altitudes.

(5) Selection of a particular site for sensor installation requires detailed on-site analysis and should not be made solely on the basis of terrain models.

2.0 COVERAGE MAPS

Graphical coverage data has been supplied by ECAC in the form of: (1) Composite Coverage Maps at specific altitudes above MSL, and (2) Route Coverage Plots of minimum coverage altitude along specific routes. Route coverage plots represent vertical slices through the coverage volume, whereas composite coverage maps are essentially horizontal cuts at fixed altitudes. These graphical results are based upon quantized topographic data (ignoring buildings*) for a grid spacing of 30 sec latitude x 30 sec longitude (roughly 1/2 mile x 1/2 mile). A four point linear interpolation estimates terrain altitudes between grid points. Atmospheric refractivity is modeled by assuming an effective earth's radius which is 4/3 the actual earth radius [1]. This allows radio waves to be drawn as straight lines over a 4/3 radius earth.

2.1 Composite Coverage Maps

Line of sight coverage is illustrated in Figure 2.1.a. The unshaded region represents the covered volume for the region in which the DABS sensor can detect aircraft. The Target Acquisition Model (TAM) [2],[3],[4] coverage approximation used by ECAC for this study is illustrated in Figure 2.1.b. Coverage is assumed to be provided for all altitudes (even altitudes below ground level) between the sensor and the terrain feature subtending the greatest angle to the sensor. The results are thus not applicable for a detailed low altitude coverage study. For example, a nearby airport in the valley between the two peaks in Figure 2.1a would not be well covered but the TAM model would indicate that it is.

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*See Section 3 for the effect buildings have upon coverage provided by the Boston ASR.

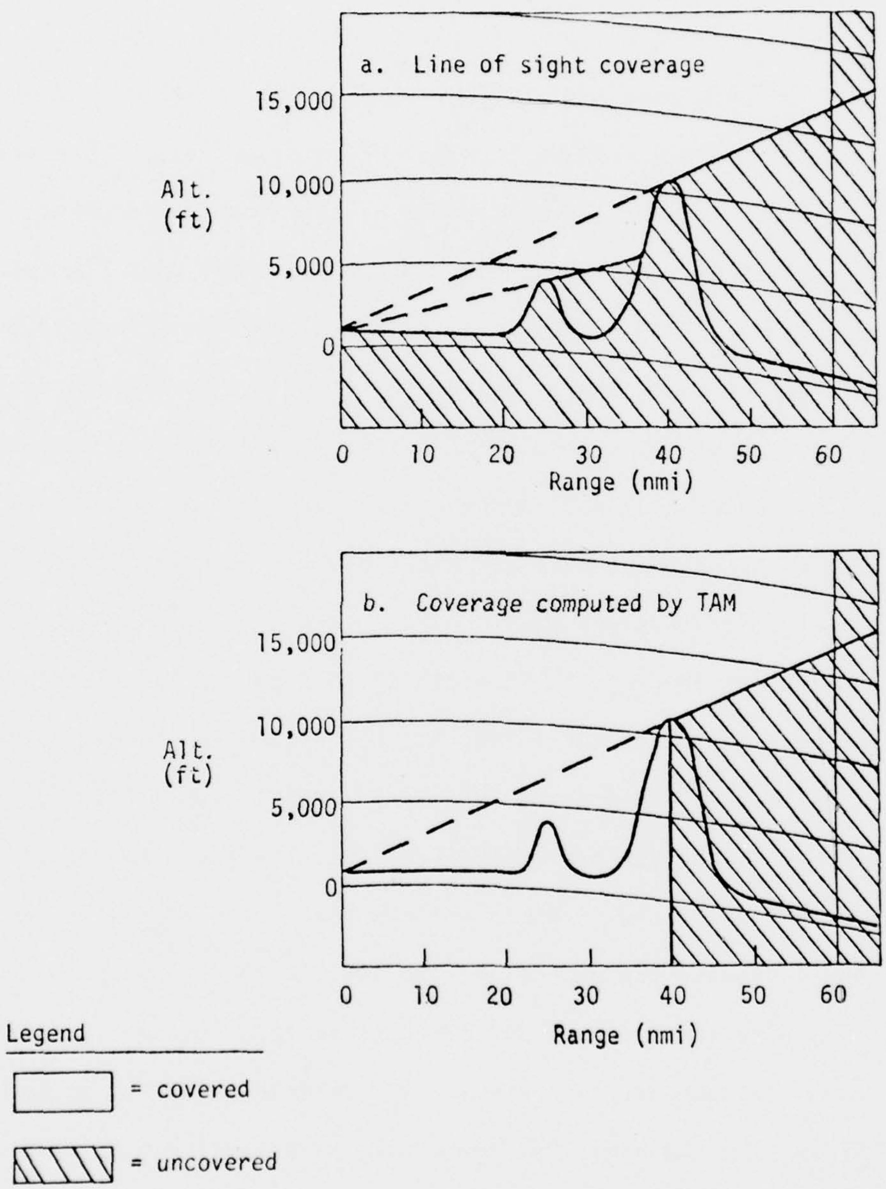

Fig.2.1. Line of sight coverage and TAM approximation. Maximum sensor range = 60 nmi.

For results presented here, a simple model was adopted in which the sensor antenna characteristics and nearby buildings limit the coverage to elevation angles in excess of $1/4^{\circ}$ above the horizontal*. If β, the elevation angle of the terrain feature limiting the horizon, is less than $1/4^{\circ}$ then coverage is as illustrated in Figure 2.2. If $\beta \geq 1/4^{\circ}$ then Figure 2.1b is applicable.

The ASRs and ARSRs existing in 1974 and the proposed ASRs and ARSRs are listed in Tables A.1-A.4 and located on a map of the U.S. in Figs. A.1-A.4. Each of these four groups of sensors are considered separately in the composite coverage maps in Figs. A5-A40. Each coverage map is for a constant altitude above sea level; altitudes 3000, 5000, 10000, 15000, and 20000 feet have been considered. Maximum sensor ranges of 60, 100, 150, and 200 have also been considered. To permit quick retrieval of the desired map, the figure numbers and corresponding parameters are listed in Table A.5. Summary coverage statistics appear in Figs. 1.2-1.5 of Section 1.

Figure 2.3 depicts the lowest altitude above sensor level (or above sea level for a sensor at sea level), as a function of range, that a sensor can cover for a smooth 4/3 earth model under the above assumptions. For a given MSL altitude, the coverage ranges in Figs. A5-A40 (which include terrain blockage and sensors above sea level) will always be less than depicted in Fig. 2.3.

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*A better choice for the ARSRs might have been a cut-off angle on the order of $-1/4^{\circ}$ since ARSRs are usually well sited - frequently on top of a hill or mountain with few buildings around them.

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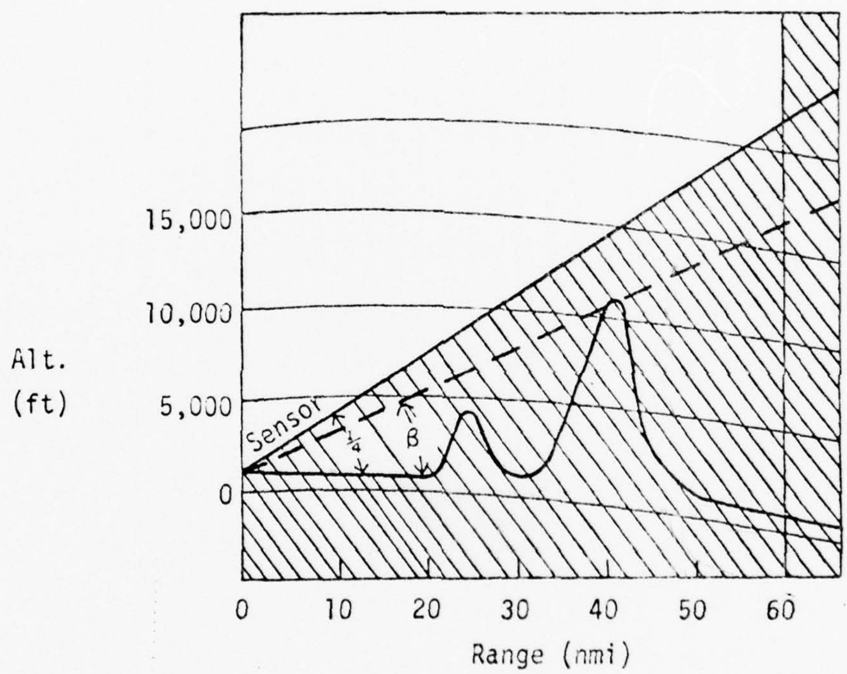

Fig.2.2. Modified TAM coverage with 1/4° cutoff angle.

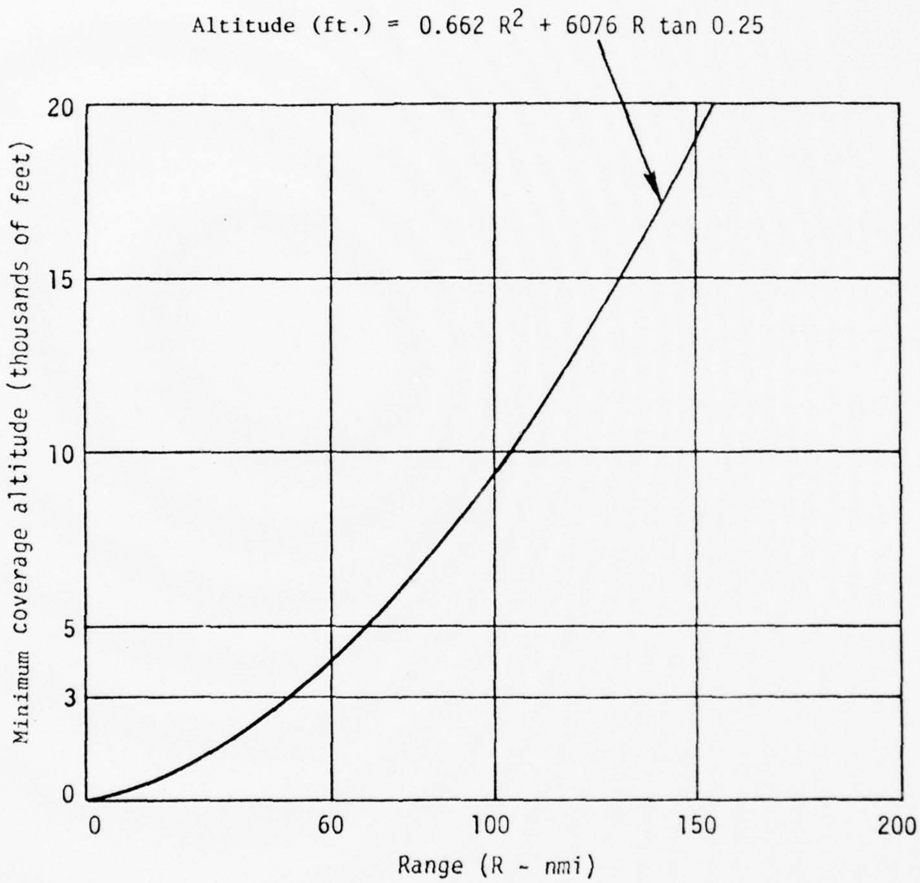

Fig.2.3. Minimum coverage altitude above sensor level for a smooth 4/3 earth model and 1/4° elevation cutoff angle.

Sensor height used was the present ASR or ARSR height above ground level (from the ECAC data file). For the proposed ASR locations, the sensor height used was 50 ft; 50 , 80, or 100 ft. was used as the sensor height for the proposed ARSRs. Changes in sensor height may be expected to have a significant effect upon coverage.

2.2 Route Coverage Plots

Route coverage plots partially determine: (1) the minimum MSL altitude at which continuous coverage is provided, and (2) how extensive are the regions of airspace visible from multiple sensors.

Fig. 2.4 is a "route coverage plot" depicting present-day coverage on a route from Boston to Washington, D.C. which passes very near to New York, Philadelphia, and Baltimore at intermediate points. In a route coverage plot, attention is limited to a one-dimensional ground track, which together with altitude constitutes a vertical slice through airspace. An aircraft is assumed to be covered if it falls in the unshaded region of Fig. 2.1.a. The term "route coverage plot" should not be taken to imply that only en route coverage is of interest, for in fact terminal coverage was of no less interest in this investigation. The limitation to a single ground track in any one plot is only a means of limiting attention to two dimensions for plotting purposes.

The sensors in question are the 1974 ASR sensors without any range limitation. A map showing the route and the sensors is given in Fig. 2.5.

Fig. 2.6 gives cumulative coverage distributions, derived from Figure 2.4. At least single coverage is provided at all points above 1300 ft. (above MSL), and at least triple coverage is provided at all points above 3700 ft. (above MSL).

Route coverage plots provide a good means for dipicting the results of this analysis technique for the heavily used routes.

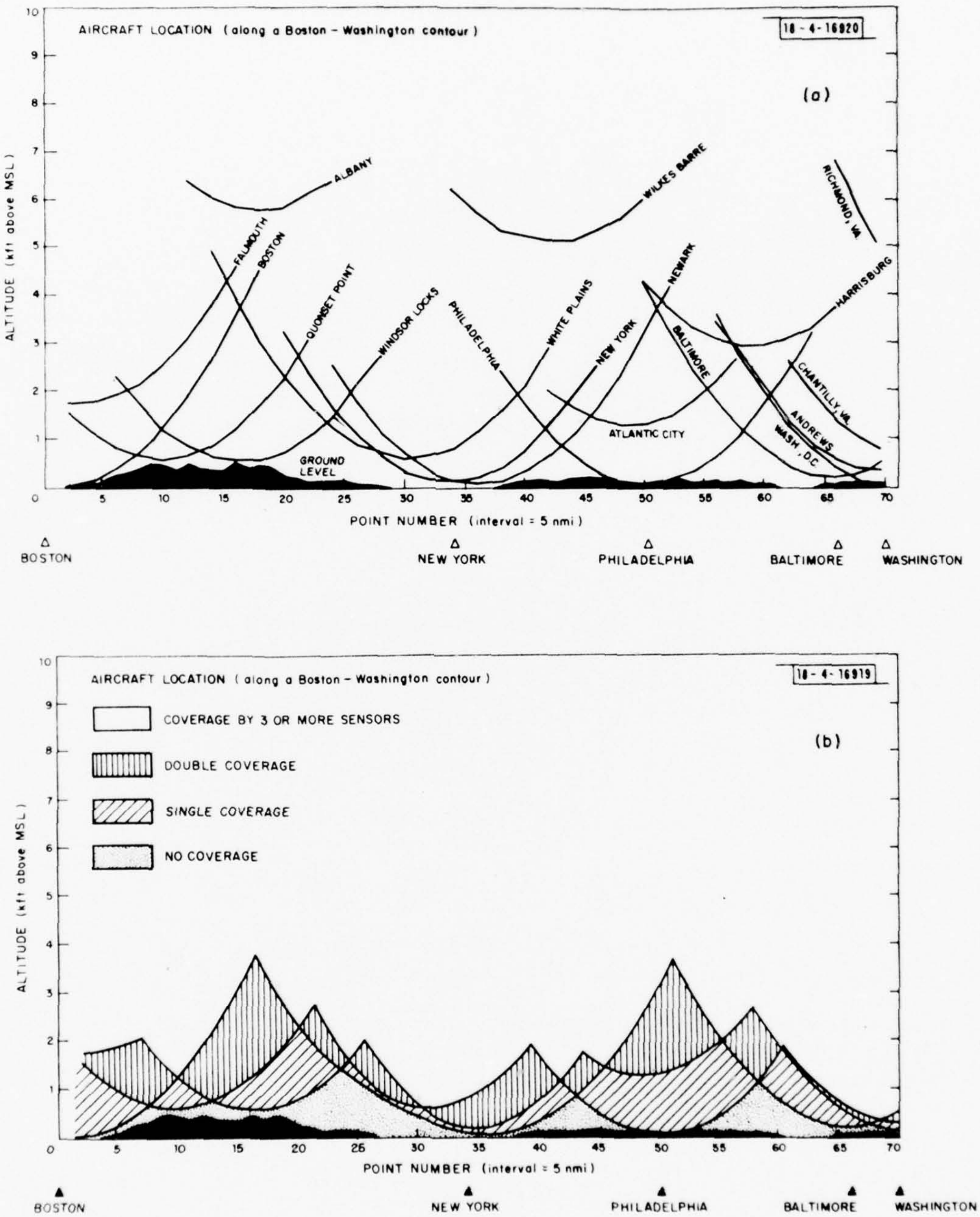

Fig.2.4. ASR route coverage plot for Boston to Washington ($1/4^{o}$ elevation cutoff angle): (a) Coverage provided by present FAA ASR sites, (b) Coverage multiplicity.

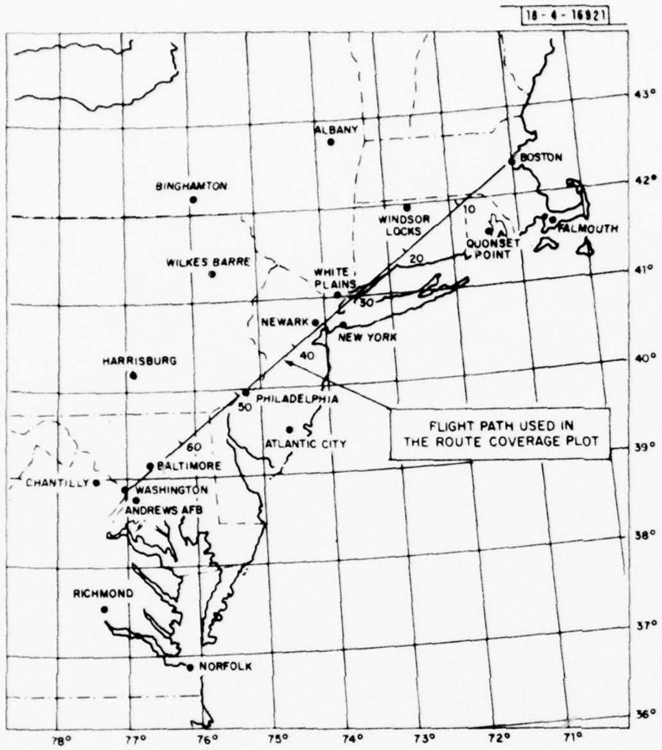

Fig.2.5. Map of sensors and flight path (flight path described by line latitude = (42° 25' 00") − χ(3° 35' 00"); longitude = (71° 00' 00") + χ(6° 00' 00") for $0 \leq \chi \leq 1$).

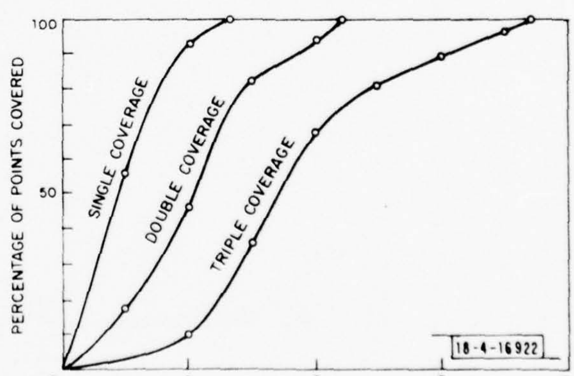

Fig.2.6. Cumulative coverage distributions over the Boston-Washington contour.

3.0 BOSTON ASR STUDY

3.1 Effect of Near-In Buildings

To assess the effect of not including man-made obstructions in the ECAC terrain models, the horizon elevation angle, as measured with a transit, and the radio horizon angle as computed using the ECAC terrain models, have been compared for a sensor at ground level (transit and hypothetical sensor both placed 63 feet west of the present Boston ASR location). These results are illustrated in Fig. 3.1. Note that over much of the horizon there is little resemblance between measured and computed results. Much of this difference is obviously due to the close proximity of the buildings in downtown Boston, bridges, buildings at the airport, and trees.

Attempts were made to improve upon the ECAC model by more realistically accounting for the buildings. These methods, tried on the Boston ASR coverage calculations, met with limited success* and are discussed below.

The effect of buildings at short range on the horizon angle is depicted in Fig. 3.2. As expected, small buildings close to the sensor have a significant effect upon the horizon angle. The ECAC model of the terrain surrounding the Boston ASR is characterized by short ranges to the terrain features limiting the line-of-sight (see Figure 3.3). This is reasonable since there are few tall hills at long range. Small buildings at short range would thus be expected to have a significant effect upon the horizon angle.

To test the sensitivity of the ECAC model to close-in small buildings, the radio horizon angle was recomputed with two changes: (1) all terrain greater

*They were not used in the CONUS coverage projections presented in Section 1, and 2.

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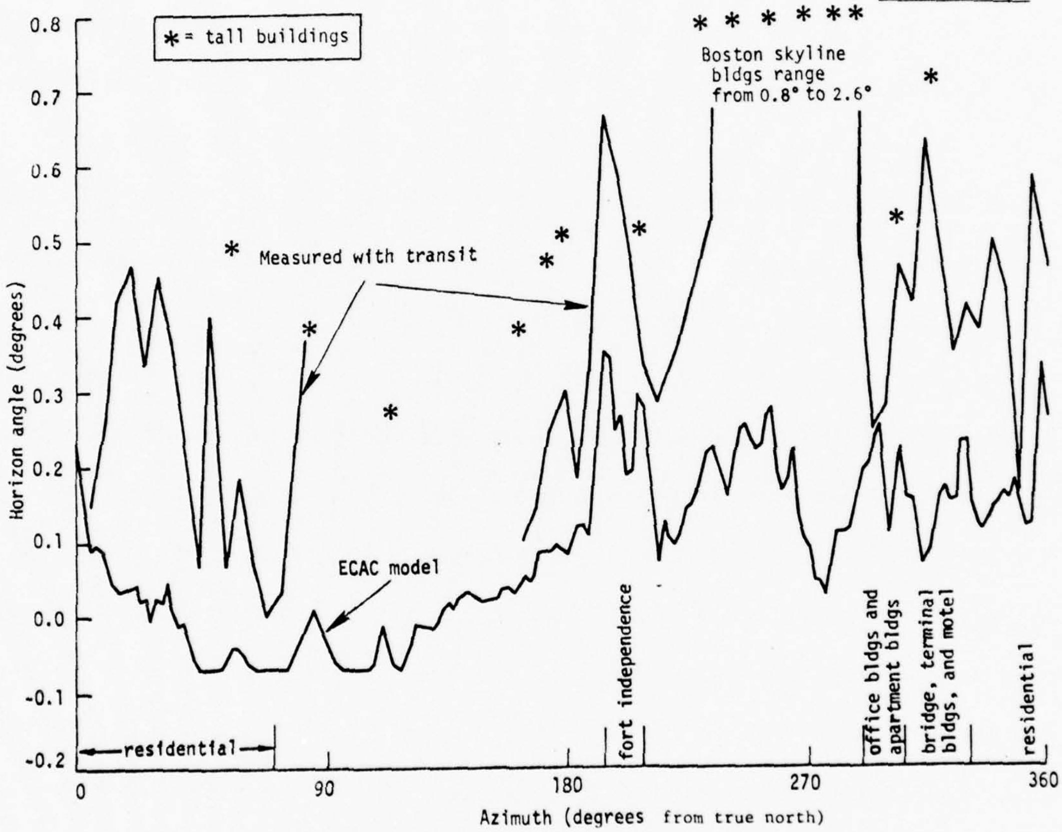

Fig.3.1. Horizon angles from ECAC model compared to optical measurements for a point 63 ft. west of Boston ASR at ground level.

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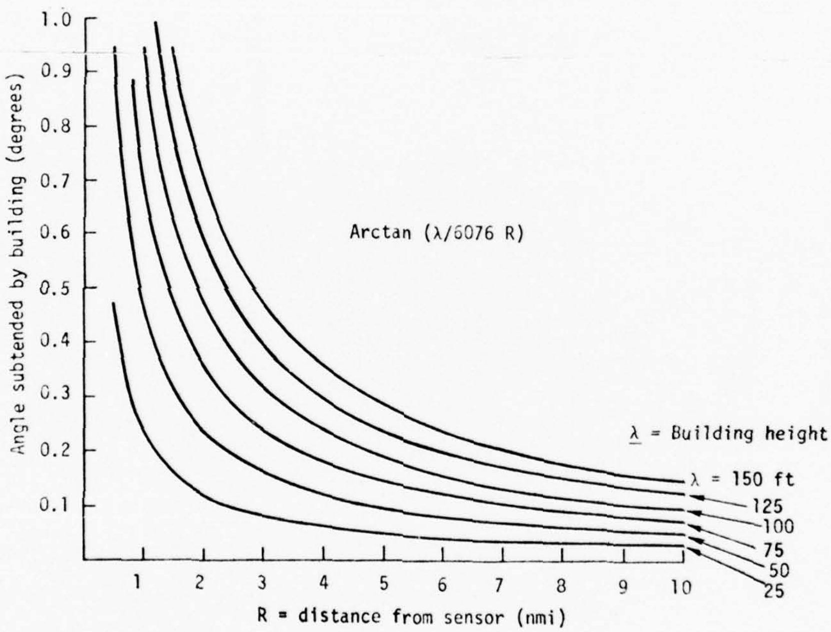

Fig.3.2. Effect of buildings at short ranges on the horizon angle.

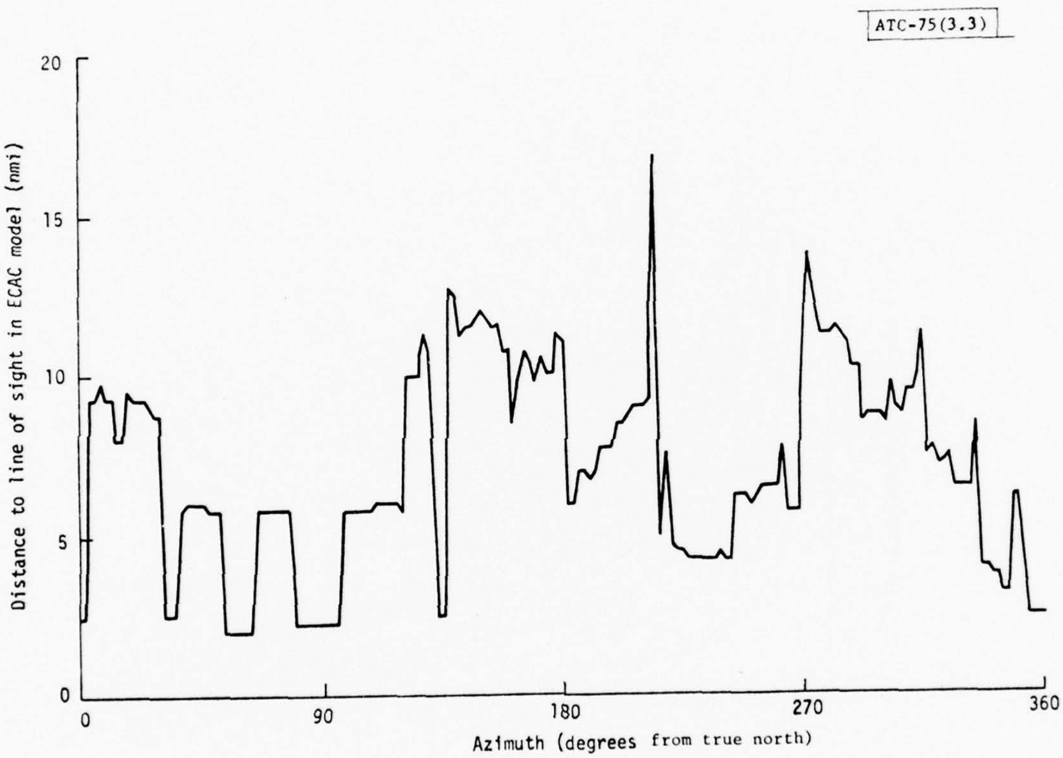

Fig.3.3. Distance to the line of sight terrain feature in the ECAC model for Boston ASR.

than 4 nmi from the sensor was raised 50 feet when computing the radio horizon angle, and (2) if the terrain feature limiting the radio horizon angle was less than 4 nmi from the sensor (with the assumption in (1)), then 50 feet were added to the height of this terrain feature in computing the radio horizon angle. These ECAC model results are compared to the measured data in Fig. 3.4. Note that there is better but still not good agreement.

3.2 Terrain Sampling Granularity

Finally, the method used to compute terrain height was considered as a possible source of error. As illustrated in Fig. 3.5, the ECAC terrain model takes points on a 30 sec x 30 sec grid, and a 4 point linear interpolation is used to estimate terrain height between grid points. Thus, as illustrated in Fig. 3.5, the estimated and actual terrain height for Point A can differ significantly. To determine the significance of this difference, the radio horizon angle was recalculated using the maximum of 4 points to estimate the terrain (i.e., Point A in Fig. 3.5 was taken to be 700 ft. instead of 575 ft.). These results are compared in Fig. 3.6. Note that the differences are small, and thus it may be concluded that the linear 4 point interpolation was a good technique considering the close spacing of grid points. This method should also be checked in mountainous terrain.

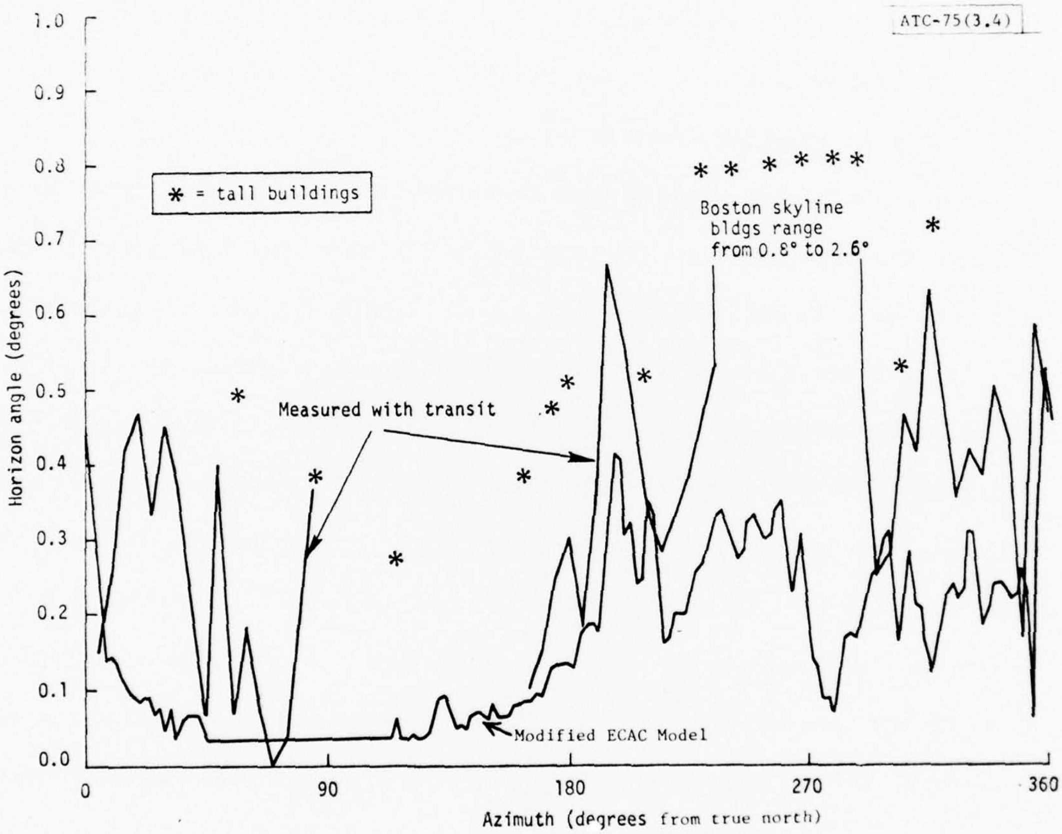

Fig.3.4. Horizon angle from ECAC model with terrain raised 50 feet compared to optical measurements.

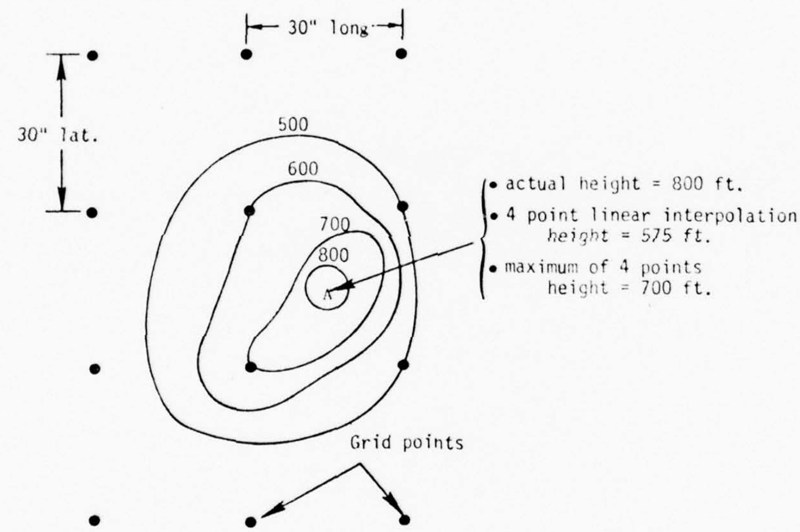

Fig.3.5. Interpolation of grid points for hypothetical terrain.

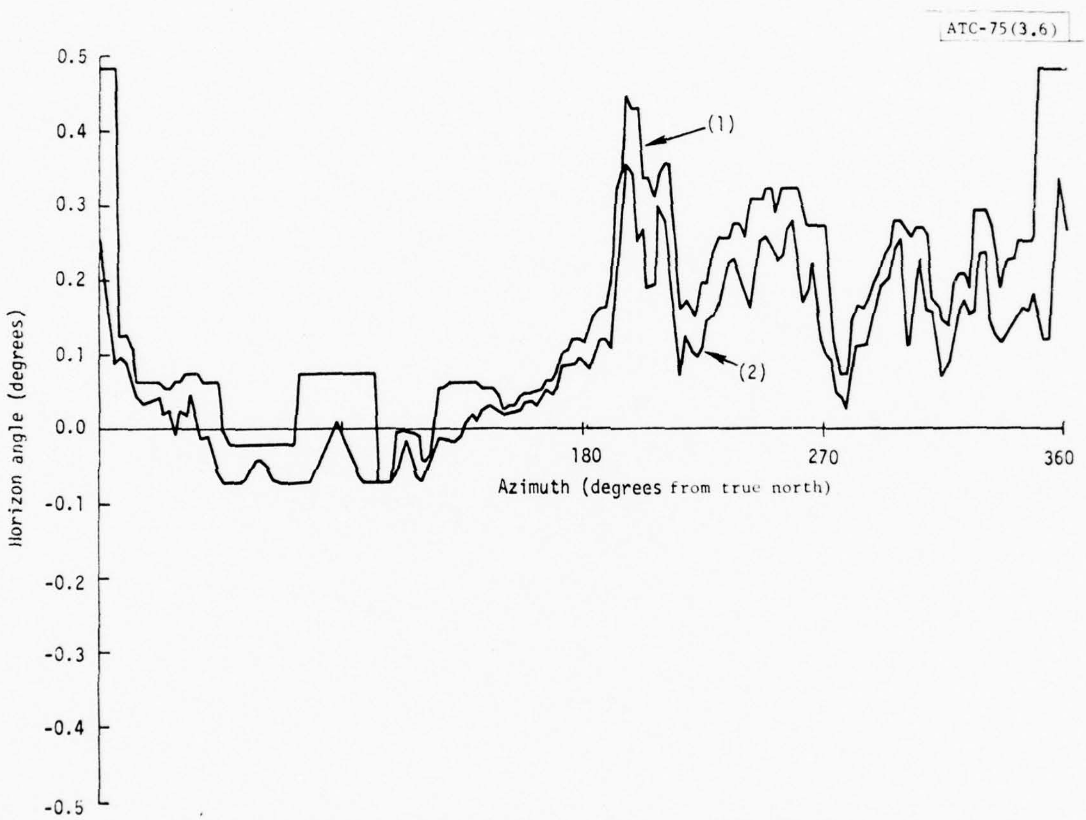

Fig.3.6. Horizon angle from ECAC model using (1) maximum of 4 points terrain interpolation and (2) 4 point linear interpolation.

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[2]. "Topographic Analysis Handbook", Electromagnetic Compatibility Analysis Center, ECAC-HDBK-75-15, (February 1975).

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APPENDIX A

SITE DATA AND COVERAGE MAPS

Table A.1. ASR Listing - 1974

Location (Lat, Long, Ground Level (ft. MSL), Sensor Height (ft. above ground level)

BIRMINGHAM AL	333424N	864525W	775.	55.
HUNTSVILLE AL	343838N	864708W	623.	31.
MAXWELL AFB AL	322319N	0862136W	162.	44.
MOBILE AL	304126N	0881455W	246.	46.
DAVIS MONTHN AFB AZ	320936N	1105310W	2705.	30.
PHOENIX AZ	332604N	1120018W	1105.	56.
LITTLE ROCK AR	344347N	0921406W	257.	52.
BURBANK CA	341215N	1182114W	743.	70.
EDWARDS AFB CA	345222N	1175438W	2335.	32.
EL TORO CA	333947N	1174246W	400.	49.
FRESNO AIR TERM CA	364651N	1194306W	332.	50.
LEMOORE NAS	362045N	1195419W	235.	37.
LONGBEACH CA	334909N	1180816W	58.	55.
LOS ANGELES CA	335557N	1182423W	126.	54.
LOS ANGELES CA	335714N	1182428W	116.	34.
MARYSVILLE CA	390749N	1212735W	86.	29.
MC CLELLAN AFB CA	383956N	1212414W	81.	50.
MIRAMAR CA	325229N	1170823W	451.	74.
MONTEREY CA	363516N	1215109W	257.	50.
MTN VIEW CA	372500N	1220300W	90.	33.
OAKLAND CA	374223N	1221327W	6.	54.
ONTARIO CA	340315N	1173541W	995.	55.
COLORADO SPRINGS	384902N	1044243W	6160.	55.
DENVER CO	394554N	1045401W	5296.	30.
WINDSOR LOCKS CT	415619N	724102W	173.	24.
WASHINGTON DC	385142N	770202W	11.	27.
FT LAUDERDALE FL	260404N	0800911W	14.	30.
JACKSONVILLE FL	302931N	0814132W	28.	36.
MIAMI FL	254751N	0801727W	9.	32.
ORLANDO FL	283256N	0811948W	112.	50.
PENSACOLA FL	302150N	0871842W	15.	54.
TAMPA FL	275749N	0823118W	25.	55.
W PALM BEACH FL	264105N	0800607W	17.	41.
ATLANTA GA	333907N	0842548W	1045.	30.
AUGUSTA GA	332150N	815727W	114.	60.
ROBINS AFB GA	323844N	0833618W	311.	55.
SAVANNAH GA	320008N	810841W	42.	24.
CHICAGO IL	415838N	875529W	663.	29.
CHICAGO OHARE INTL	415850N	875541W	667.	54.
CHICAGO SOUTH IL	413717N	874610W	667.	54.
MOLINE IL	412618N	0902951W	589.	30.
PEORIA IL	403936N	894204W	660.	54.

Table A.1. (continued)

SPRINGFIELD IL	395027N	894124W	598.	54.
FT WAYNE MUNI IN	405922N	851216W	802.	50.
INDIANAPOLIS IN	394344N	861709W	794.	40.
SO BEND IN	414223N	861931W	786.	37.
CEDAR RAPIDS IA	415241N	0914228W	863.	54.
DES MOINES IA	413226N	0933909W	954.	60.
SIOUX CITY IA	422408N	0962341W	1097.	54.
WICHITA KS	373906N	0972503W	1308.	34.
COVINGTON KY	390234N	843916W	860.	62.
LEXINGTON KY	380158N	843541W	976.	32.
LOUISVILLE KY	381038N	854326W	497.	60.
SHEREVEPORT LA	323045N	0933932W	167.	27.
BATON ROUGE LA	303209N	0910859W	71.	30.
NEW ORLEANS LA	295937N	0901530W	17.	77.
ANDREWS AFB MD	384844N	765202W	271.	31.
BALTIMORE MD	391044N	764103W	157.	30.
BOSTON MA	422055N	710022W	17.	36.
FALMOUTH MA	413944N	703123W	123.	27.
DETROIT MI	421351N	832148W	640.	62.
FLINT MI	425723N	834440W	781.	54.
GRAND RAPIDS MI	425254N	853124W	790.	50.
LANSING MI	424700N	843518W	955.	67.
SAGNIAW MI	433102N	840430W	667.	30.
MINNEAPOLIS MN	445325N	0931351W	850.	30.
ROCHESTER MN	435435N	0923007W	1316.	54.
JACKSON MS	321820N	0900500W	316.	61.
MERIDIAN MS	323335N	0883416W	337.	45.
KANSAS CITY MO	391134N	0943812W	945.	47.
ST LOUIS MO	384426N	0902214W	601.	65.
BILLINGS MT	454825N	1083332W	3671.	27.
GREAT FALLS MT	473005N	1110944W	3462.	32.
LINCOLN AFB NE	405027N	0964611W	1158.	62.
OMAHA NE	410835N	0955413W	1212.	68.
LAS VEGAS NV	360505N	1150932W	2171.	25.
RENO INTL NV	392939N	1194559W	4396.	28.
ATLANTIC CITY NJ	393720N	743542W	73.	28.
NEWARK NJ	404143N	741022W	8.	51.
ALBUQUERQUE NM	350215N	1063702W	5318.	24.
ALBANY NY	424444N	734756W	320.	51.
BINGHAMTON NY	421250N	755845W	1581.	57.
BUFFALO NY	425626N	784411W	711.	37.
NEW YORK NY	403811N	734603W	12.	33.
ROCHESTER NY	430714N	773955W	542.	31.

Table A.1. (continued)

ROME NY	431341N	752527W	578.	41.
SYRACUSE NY	430644N	760620W	400.	25.
WHITE PLAINS NY	410340N	734255W	490.	41.
ASHEVILLE NC	352631N	823226W	2230.	70.
CHARLOTTE NC	351236N	805629W	600.	70.
FAYETTEVLE MUNI NC	345824N	785228W	170.	61.
GREENSBORO NC	360536N	795601W	932.	50.
RALEIGH NC	355313N	784707W	417.	65.
FARGO ND	465513N	0964812W	1498.	30.
AKRON OH	405505N	812638W	1210.	30.
CLEVELAND OH	412449N	815107W	789.	31.
COLUMBUS OH	395959N	825344W	812.	65.
DAYTON OH	394900N	840200W	926.	72.
TOLEDO OH	413515N	834810W	670.	50.
YOUNGSTOWN OH	411528N	804040W	1156.	47.
TINKER AFB OK	352535N	0972314W	1270.	51.
TULSA OK	361206N	0955328W	642.	30.
PORTLAND INTL OR	453456N	1223612W	23.	53.
ERIE PA	420500N	801038W	732.	30.
HARRISBURG PA	401324N	765239W	494.	29.
PHILADELPHIA PA	395232N	751401W	9.	28.
PITTSBURGH PA	402953N	801440W	1243.	30.
WILKES BARRE PA	412009N	754310W	1037.	47.
QUONSET PT RI	413608N	712440W	10.	28.
CHARLESTON SC	325425N	800225W	45.	55.
GREENVILLE SC	345059N	822121W	1007.	47.
W COLUMBIA SC	335658N	810750W	236.	60.
SIOUX FALLS SD	433438N	0964427W	1428.	54.
ALCOA TN	354829N	835905W	989.	61.
BRISTOL TN	362822N	822414W	1537.	55.
CHATTANOOGA TN	350155N	851227W	698.	47.
MEMPHIS TN	350354N	0895713W	291.	48.
NASHVILLE TN	360725N	864052W	597.	67.
AMARILLO TX	351341N	1014235W	3602.	30.
AUSTIN TX	301244N	0973954W	590.	17.
COLLEYVILLE TX	325250N	0970707W	650.	54.
CORPUS CHRISTI TX	274357N	0972348W	32.	41.
DALLAS TX	325435N	0964501W	487.	50.
DALLAS TX	325141N	0964501W	633.	40.
DYESS AFB TX	322600N	0995059W	1753.	30.
EL PASO TX	314832N	1062138W	3956.	36.
FT. WORTH TX	322419N	970244W	596.	30.
HOUSTON TX	294840N	0951452W	42.	90.
LUBBOCK TX	334005N	1015110W	3300.	25.

Table A.1. (continued)

MIDLAND TX	315748N	1021150W	2730.	30.
SAN ANTONIO TX	293125N	0982841W	805.	55.
HILL AFB UT	410710N	1115945W	4770.	26.
SALT LAKE CITY UT	404623N	1115833W	4220.	27.
BURLINGTON INTL VT	442800N	730900W	335.	50.
CHANTILLY VA	385724N	772750W	295.	37.
NORFOLK VA	365344N	761137W	25.	55.
RICHMOND VA	373019N	771928W	157.	35.
ROANOKE VA	371932N	795856W	1137.	37.
FAIRCHILD AFB WA	473721N	1173927W	2462.	55.
MC CHORD AFB WA	470819N	1222815W	420.	29.
SEATTLE WA	472707N	1221850W	406.	51.
HUNTINGTON WV	382227N	823402W	844.	31.
CHARLESTON WV	382144N	813523W	982.	50.
GREEN BAY WI	442935N	880719W	675.	90.
MADISON WI	430822N	0892016W	862.	30.
MILWAUKEE WI	425704N	875352W	667.	65.

Table A.2. ARSR Listing - 1974

Location (Lat, Long, Ground Level (ft. MSL),
Sensor Height (ft. above ground level)

RAMER AL	321238N	0861001W	276.	60.
PHOENIX ARSR AZ	335848N	1114742W	5239.	65.
RUSSELLVILLE AR	352400N	0925950W	1093.	72.
TEXARKANA AFS AR	332717N	0935954W	367.	45.
BORON CA	350455N	1173453W	2994.	123.
HALF MOON BAY CA	373144N	1222535W	1930.	82.
MT. LAGUNA AFS CA	325233N	1162451W	6269.	66.
PASO ROBLES CA	352344N	1202112W	3625.	66.
RRED BLUFF AFS CA	400847N	1221813W	483.	53.
SACRAMENTO CA	383314N	1211609W	130.	45.
SAN PEDRO HILL CA	334446N	1182009W	1480.	60.
DENVER CO	393539N	1044135W	6150.	55.
GRAND JUNCTION CO	390418N	1083327W	9000.	56.
TRINIDAD ARSR CO	373230N	1040020W	5503.	59.
KEY WEST FL	243501N	814118W	9.	65.
MACDILL AFB FL	275005N	822820W	10.	66.
PATRIC AFB FL	281250N	0803558W	10.	52.
RICHMOND AFS FL	253724N	0802418W	12.	97.
TYNDALL AFB FL	300435N	853632W	28.	52.
WHITEHOUSE FIELDFL	302045N	0815225W	91.	46.
ATLANTA GA	335339N	842955W	1090.	70.
VALDOSTA GA	305831N	0831249W	325.	50.
ASHTON ID	443341N	1112636W	9904.	60.
BOISE ID	432640N	1160808W	8320.	57.
CHICAGO IL	414750N	875129W	615.	111.
HANNA CITY AFS IL	404000N	894500W	650.	85.
INDIANAPOLIS IN	394446N	861704W	784.	60.
LAGRANGE IN	413752N	852453W	979.	110.
W BRANCH IA	414221N	0911505W	800.	48.
HUTCHINSON AFS KS	375524N	0975414W	1536.	67.
OLATHE KS	385012N	0945413W	1055.	90.
SUBLETTE KS	373953N	1005216W	2940.	58.
LYNCH KY	365458N	825326W	4150.	106.
ALEXANDRIA LA	311853N	0923141W	89.	78.
NEW ORLEANS LA	302050N	0894650W	28.	75.
BUCKS HARBOR ME	443741N	672344W	221.	118.
FT HEATH MA	422321N	705811W	60.	95.
SUITLAND MD	385114N	765622W	285.	60.
DETROIT MI	421636N	832827W	683.	77.
EMPIRE AFS MI	444807N	860303W	1003.	56.
MINNEAPOLIS MN	444510N	0931338W	1110.	69.

Table A.2 (continued)

BYHALIA MS	345108N	0894556W	390.	33.
MOSCOW MS	324308N	885040W	667.	65.
UKIRKSVILLE AFS MO	401752N	0923431W	982.	50.
ST LOUIS MO	384204N	0902326W	706.	85.
KALISPELL MT	480041N	1142149W	6785.	40.
MALMSTROM AFB MT	473007N	1111209W	3525.	71.
HASTINGS NE	403448N	981720W	1900.	68.
NO PLATTE NE	404958N	1004452W	3161.	63.
OMAHA NE	412137N	0960130W	1305.	51.
ANGEL PEAK NV	361907N	1153430W	8865.	59.
BATTLE MOUNTAIN NV	402411N	1165202W	9601.	125.
FALLON AFS NV	392420N	1184316W	3926.	139.
TONOPAH NV	380830N	1171158W	7200.	160.
ELWOOD CITY NJ	393519N	744156W	119.	65.
ALBUQUERQUE NM	350417N	1065412W	5933.	30.
GALLUP ARSR NM	360435N	1085135W	9373.	72.
MESA RICA NM	361417N	1041214W	5373.	62.
SILVER CITY NM	324700N	1081600W	7620.	58.
DANSVILLE NY	423816N	773914W	2027.	65.
NEW YORK NY	403945N	734648W	10.	110.
SARATOGA SPR AFSNY	430037N	734057W	605.	72.
BENSON NC	353030N	783330W	282.	68.
MAIDEN NC	353642N	811424W	889.	77.
BRECKSVILLE OH	411805N	814103W	1247.	115.
LONDON OH	395045N	832848W	1086.	118.
OKLAHOMA CITY OK	352402N	0973711W	1284.	69.
OKLAHOMA CITY AFS	352408N	0972133W	1331.	75.
KENO AFS OR	420410N	1215815W	6600.	42.
SALEM OR	445524N	1233424W	3740.	70.
BENTON AFS PA	412126N	761736W	2381.	122.
OAKDALE AD SITE PA	402356N	800926W	1270.	120.
TREVOSE PA	400805N	745914W	200.	53.
AIKEN AFS SC	333847N	0814037W	530.	72.
JEDBURG SC	330412N	801314W	50.	63.
GETTSBURG AFS SD	450303N	0995720W	2400.	120.
JOELTON TN	362010N	865140W	846.	72.
AMARILLO AFB TX	351448N	1013919W	3618.	40.
EL PASO TX	314053N	1061150W	4019.	90.
FT WORTH TX	325640N	0971312W	684.	70.
HOUSTON TX	293715N	0951021W	42.	108.
ODESSA TX	323315N	1022545W	3117.	93.
OILTON TX	272955N	0985805W	880.	60.

Table A.2. (continued)

SAN ANTONIO TX	292308N	0983800W	784.	53.
CEDAR CITY UT	373536N	1125144W	10691.	83.
SALT LAKE CITY UT	410201N	1115016W	9515.	70.
BEDFORD AFS VA	373102N	793039W	4226.	46.
CAPE CHARLES AFSVA	370802N	755704W	9.	110.
MICA PEAK AFS WA	473426N	1170450W	5205.	42.
SEATTLE WA	473922N	1222443W	355.	105.
HORICON WI	432646N	882930W	1188.	78.
LOVELL WY	444900N	1075406W	9557.	56.
LUSK WY	423535N	1043515W	6100.	40.
ROCK SPRINGS WY	412605N	1090700W	8663.	55.

Table A.3. Proposed ASR Listing

Location (Lat, Long, Ground Level (ft. MSL), Sensor Height (ft. above ground level)

DOTHAN AL	311900N	0852700W	400.	50.
FLAGSTAFF AZ	350800N	1114000W	7012.	50.
PRESCOTT MUNI AZ	344209N	1124627W	5042.	50.
FAYETTEVILLE AR	362639N	0940619W	1361.	50.
FT SMITH MUNI AR	352000N	0942200W	468.	50.
HOT SPRINGS AR	432900N	0930600W	535.	50.
TEXARKANA AFS AR	332700N	0935900W	389.	50.
ARCATA CA	405900N	1240600W	218.	50.
BAKERSFIELD CA	352600N	1190300W	491.	50.
CHICO MUNI CA	394724N	1215046W	238.	50.
EL CENTRO NAF CA	324857N	1154014W	43.	50.
PALM SPRING MUNI	335000N	1163000W	448.	50.
REDDING MUNI CA	403017N	1221726W	500.	50.
/ANTA BARBARA MUNI	342600N	1195000W	10.	50.
STOCKTON CA	375400N	1211500W	29.	50.
ASPEN CO	391300N	1065200W	7793.	50.
DURANGO CO	370900N	1074500W	6684.	50.
GRAND JUNCTION CO	390700N	1083100W	4857.	50.
PUEBLO MEM CO	381700N	1043000W	4725.	50.
BRIDGEPORT CT	411000N	730800W	9.	50.
WILMINGTON DE	394100N	753600W	79.	50.
DAYTONA BEACH FL	291100N	0810300W	34.	50.
FT MYERS FL	263500N	0815200W	18.	50.
MELBOURNE FL	280600N	0803800W	32.	50.
PANAMA CITY FL	301300N	0854100W	20.	50.
SARASOTA BRADENTON	272400N	0823300W	27.	50.
TALLAHASSEE MUNIFL	302400N	0842100W	81.	50.
TITUSVILLE FL	283100N	0804800W	35.	50.
ALBANY GA	313200N	841200W	196.	50.
AUGUSTA GA	332800N	0820200W	424.	50.
BOISE AIR TERM ID	433400N	1161400W	2858.	50.
IDAHO FALLS ID	433100N	1120400W	4740.	50.
LEWISTON PERCE ID	462300N	1170100W	1438.	50.
POCATELLO MUNI ID	425500N	1123600W	4448.	50.
CHAMPAIGN IL	400200N	881700W	754.	50.
DECATUR IL	395000N	885200W	679.	50.
QUINCY MUNI IL	395600N	0911200W	769.	50.
BLOOMINGTON IN	390800N	863700W	847.	50.
EVANSVILLE IN	380200N	873200W	418.	50.
LAFAYETTE IN	402500N	865600W	605.	50.
BURLINGTON IA	404700N	0910700W	697.	50.
DUBUQUE MUNI IA	422405N	0904232W	1076.	50.
LEXINGTON IA	380200N	843600W	979.	50.
WATERLOO MUNI IA	423300N	0922400W	870.	50.
LIBERAL MUNI KS	370240N	1005815W	2887.	50.
TOPEKA KS	390400N	0953700W	880.	50.
PADUCAH KY	370400N	884600W	410.	50.
ESLER FIELD LA	312650N	0921919W	108.	50.
LAFAYETTE LA	301200N	0920000W	42.	50.
LAKE CHARLES LA	300700N	0931300W	16.	50.
MONROE LA	323000N	0920200W	79.	50.
BANGOR INTL ME	444600N	0685000W	192.	50.
PORTLAND ME	433900N	701800W	74.	50.

Table A.3. (continued)

BARNSTABLE MUNI MA	413950N	701703W	52.	50.
NANTUCKET MEM MA	411654N	700138W	47.	50.
TEWKSBURY MA	421600N	715300W	1009.	50.
WORCHESTER MUNI MA	421627N	715256W	1009.	50.
BATTLE CREEK MI	421900N	851500W	941.	50.
BENTON HARBOR MI	420800N	862600W	643.	50.
KALAMAZOO MI	421400N	853300W	874.	50.
MUSKEGON MI	431000N	861400W	628.	50.
DULUTH INTL MN	465000N	0921100W	1429.	50.
GULFPORT CBS MS	302400N	0890400W	28.	50.
SPRINGFIELD MO	371500N	0932300W	1267.	50.
HELENA MT	463600N	1115900W	3873.	50.
MISSOULA MT	465500N	1140500W	3201.	50.
GRAND ISLAND NE	405800N	0981900W	1846.	50.
KEARNEY MUNI NE	404332N	0990017W	2130.	50.
KEENE NH	425400N	721600W	487.	50.
LEBANON REGIONALNH	434044N	721259W	1243.	50.
MANCHESTER NH	425600N	712600W	233.	50.
TRENTON NJ	401700N	744900W	213.	50.
ELMIRA NY	421000N	765400W	980.	50.
ISLIP NY	404800N	730600W	98.	50.
ROSWELL INDTL NM	331800N	1043200W	3669.	50.
SANTA FE CO MUNINM	353226N	1060352W	6344.	50.
HICKORY NC	354400N	812300W	1189.	50.
NEW BERN NC	350500N	770400W	19.	50.
ROCKY MOUNT MUNINC	355836N	774214W	97.	50.
WILMINGTON NC	341600N	775400W	31.	50.
WINSTON SLM AFS NC	360900N	801300W	969.	50.
BISMARCK MUNI ND	464700N	1004500W	1677.	50.
MINOT INTL ND	481537N	1011712W	1715.	50.
GRAND FKS INTL ND	475700N	971100W	844.	50.
BARTLESVILLE OK	364603N	0960105W	715.	50.
LAWTON MUNI OK	343400N	0982500W	1109.	50.
EUGENE OR	440700N	1231300W	365.	50.
MEDFORD OR	422200N	1225200W	1330.	50.
ALLENTOWN PA	403900N	772600W	1000.	50.
ERIE INTL PA	420500N	801100W	732.	50.
LANCASTER PA	400700N	761800W	403.	50.
WILLIAMSPT LYCO PA	411600N	765400W	1000.	50.
MYRTLE BCH MUNI SC	334900N	784400W	33.	50.
RAPID CITY RGNL SD	440300N	1030300W	3182.	50.
BEAUMONT MUNI TX	295700N	0940100W	16.	50.
COLLEGE STATION TX	303500N	0962200W	319.	50.
HARLINGEN TX	261400N	0973900W	35.	50.
JACKSON TN	353600N	885500W	433.	50.
LONGVIEW TX	322300N	0944300W	365.	50.
MILLER INTL TX	261100N	981400W	107.	50.
SAN ANGELO TX	312200N	1003000W	1915.	50.
TEMPLE TX	310900N	0972400W	682.	50.
TYLER TX	322100N	0952400W	544.	50.
WACO MUNI TX	313700N	0971400W	516.	50.
WICHITA FALLS TX	335900N	0983000W	1015.	50.
CHARLTTESVILLE VA	380800N	782700W	640.	50.
LYNCHBURG MUNI VA	372000N	791200W	942.	50.
NEWPORT NEWS VA	370600N	763000W	41.	50.
PASCO WA	461600N	1190700W	406.	50.
YAKIMA MUNI WA	463400N	1203200W	1089.	50.
CLARKSBURG WV	391600N	801400W	1203.	50.
MORGANTOWN WV	393800N	795900W	1248.	50.
PARKERSBURG WV	392100N	812600W	858.	50.
LA CROSSE MUNI WI	435300N	0911500W	653.	50.
OSHKOSH WI	435900N	883300W	805.	50.
CASPER WY	425400N	1062800W	5438.	50.
CHEYENNE MUNI WY	411200N	1044600W	1353.	50.

Table A.4. Proposed ARSR Listing

Location (Lat, Long, Ground Level (ft. MSL)
Sensor Height (ft. above ground level)

GRAND BAY AL	302831N	0882020W	100.	80.
HALEYVLE TRA AL	341200N	0873800W	925.	80.
HAVASU CITY AZ	342700N	1142200W	480.	80.
HARTFORD CT	414500N	0724200W	19.	50.
CROSS CITY FL	293800N	0830700W	40.	80.
BALDWIN GA	330800N	0831500W	385.	60.
HANNA CITY AFS IL	403200N	0894750W	724.	60.
WATERLOO MUNI IA	423330N	0922315W	920.	80.
SNOW MTN AFS KY	375350N	0860009W	900.	80.
FINLAND AFS MN	472500N	0911440W	1520.	50.
NEWPORT MS	325630N	0894615W	420.	60.
LEBANON MO	374000N	0924000W	1323.	100.
BEACH ND	465400N	1040000W	2950.	80.
FINLEY AFS ND	473100N	0975000W	1450.	80.
AFTON OK	364200N	0945700W	800.	50.
DU BOIS PA	410600N	0784600W	1817.	80.
CROSSVILLE MEM TN	354800N	850000W	1881.	50.
TIPTONVILLE TN	362100N	0893000W	280.	80.
ANSON TX	324500N	0995200W	1710.	80.
ROGERS TX	305610N	0971330W	550.	80.
GUTHRIE WV	382539N	0814100W	1179.	80.

Table A.5. Coverage Map Listing and Parameters

Figure Number	Sensor Type	MSL Altitude (thousands of feet)	Maximum Range* (nmi)
A.5	ASR	20	100
A.6	ASR	20	60
A.7	ASR	15	≥133
A.8	ASR	15	100
A.9	ASR	15	60
A.10	ASR	10	100
A.11	ASR	10	60
A.12	ASR	5	≥ 71
A.13	ASR	5	60
A.14	ASR	3	≥ 52
A.15	ARSR	20	≥156
A.16	ARSR	20	150
A.17	ARSR	20	100
A.18	ARSR	15	≥133
A.19	ARSR	15	100
A.20	ARSR	10	106
A.21	ARSR	10	100
A.22	ARSR	5	≥ 71
A.23	Proposed ASR	20	100
A.24	Proposed ASR	20	60
A.25	Proposed ASR	15	≥133
A.26	Proposed ASR	15	100
A.27	Proposed ASR	15	60
A.28	Proposed ASR	10	100
A.29	Proposed ASR	10	60
A.30	Proposed ASR	5	≥ 71
A.31	Proposed ASR	5	60
A.32	Proposed ASR	3	≥ 52
A.33	Proposed ARSR	20	≥156
A.34	Proposed ARSR	20	150
A.35	Proposed ARSR	20	100
A.36	Proposed ARSR	15	≥133
A.37	Proposed ARSR	15	100
A.38	Proposed ARSR	10	≥106
A.39	Proposed ARSR	10	100
A.40	Proposed ARSR	5	≥ 71

*Coverage maps for ranges greater than values preceded by "≥" would be identical. (Due to earth curvature; see Section 2.1 and Fig. 2.3 for further explanation.)

C44-1689

Fig. A.1. Existing ASR locations.

C44-1688

Fig. A.2. Existing ARSR locations.

Fig. A.3. Proposed ASR locations.

C44-1690

Fig. A.4. Proposed ARSR locations.

C44-1701

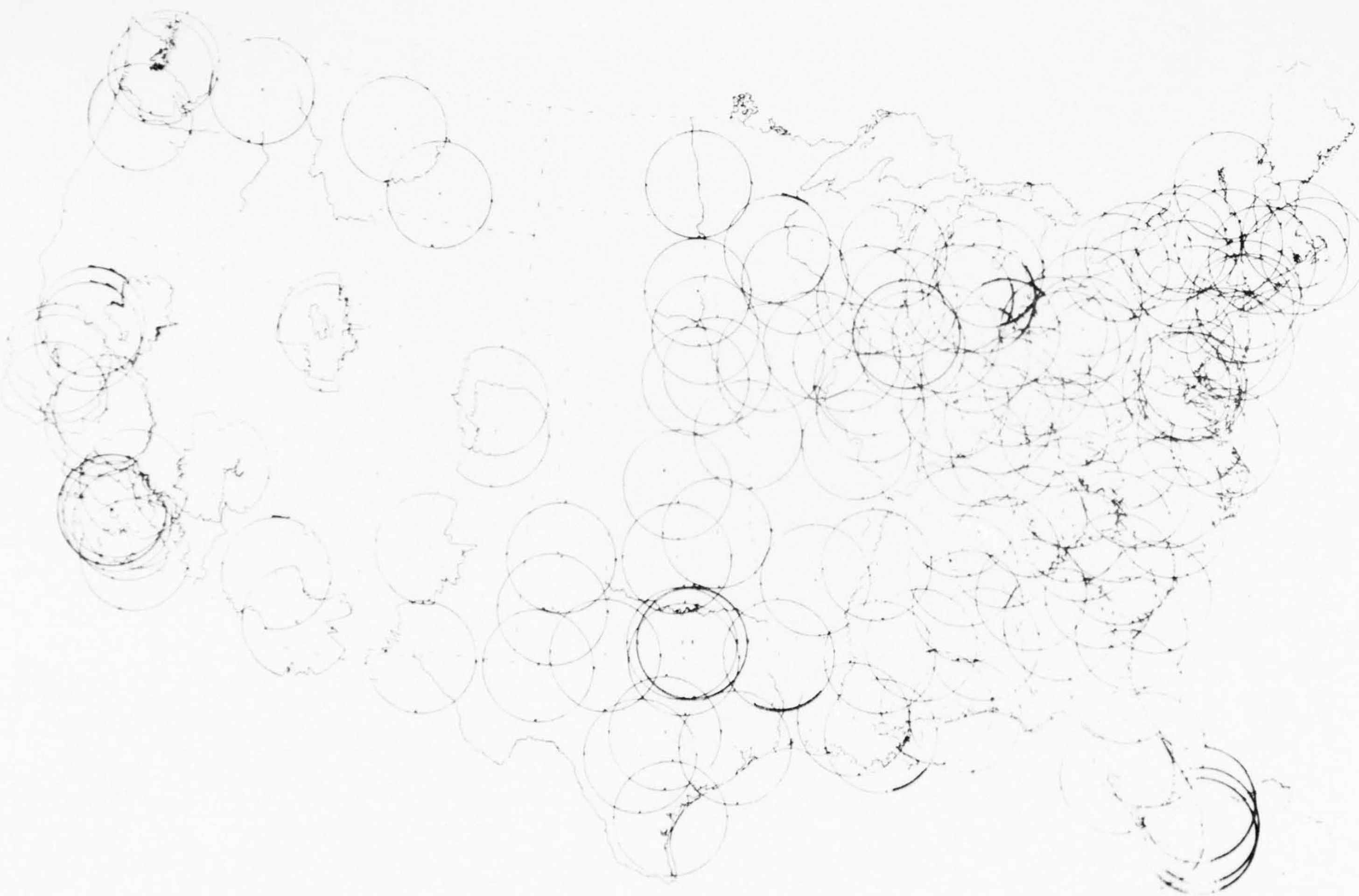

Fig. A.5. ASR composite coverage map, 20,000 ft. MSL, maximum range R_{max} = 100 nmi.

C44-1709

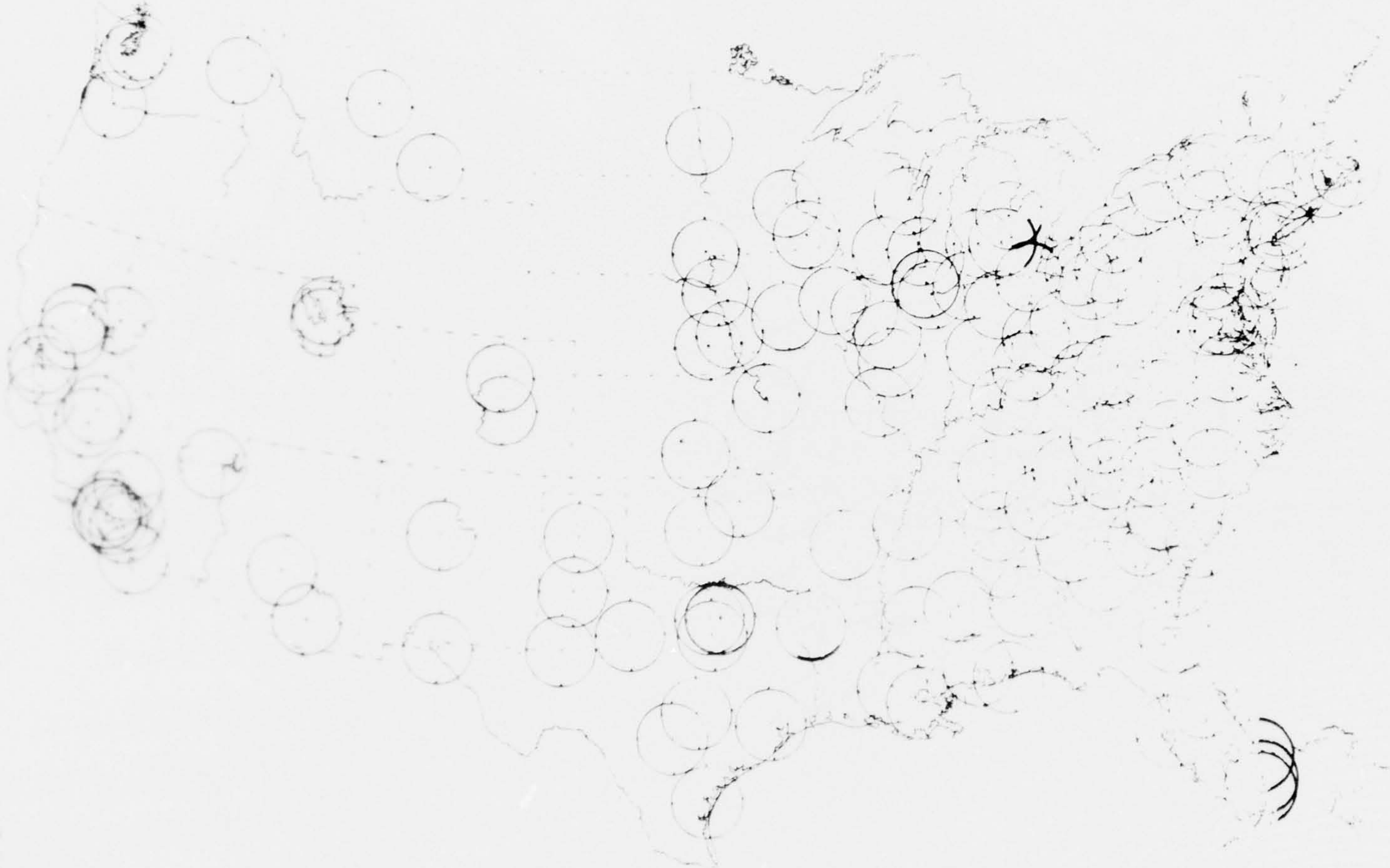

Fig. A.6. ASR composite coverage map, 20,000 ft. MSL, maximum range R_{max} = 60 nmi.

C44-1706

Fig. A.7. ASR composite coverage map, 15,000 ft. MSL, maximum range $R_{max} \geq 133$ nmi.

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C44-1707

Fig. A.8. ASR composite coverage map, 15,000 ft. MSL, maximum range R_{max} = 100 nmi.

C44-1705

Fig. A.9. ASR composite coverage map, 15,000 ft. MSL, maximum range R_{max} = 60 nmi.

C44-1702

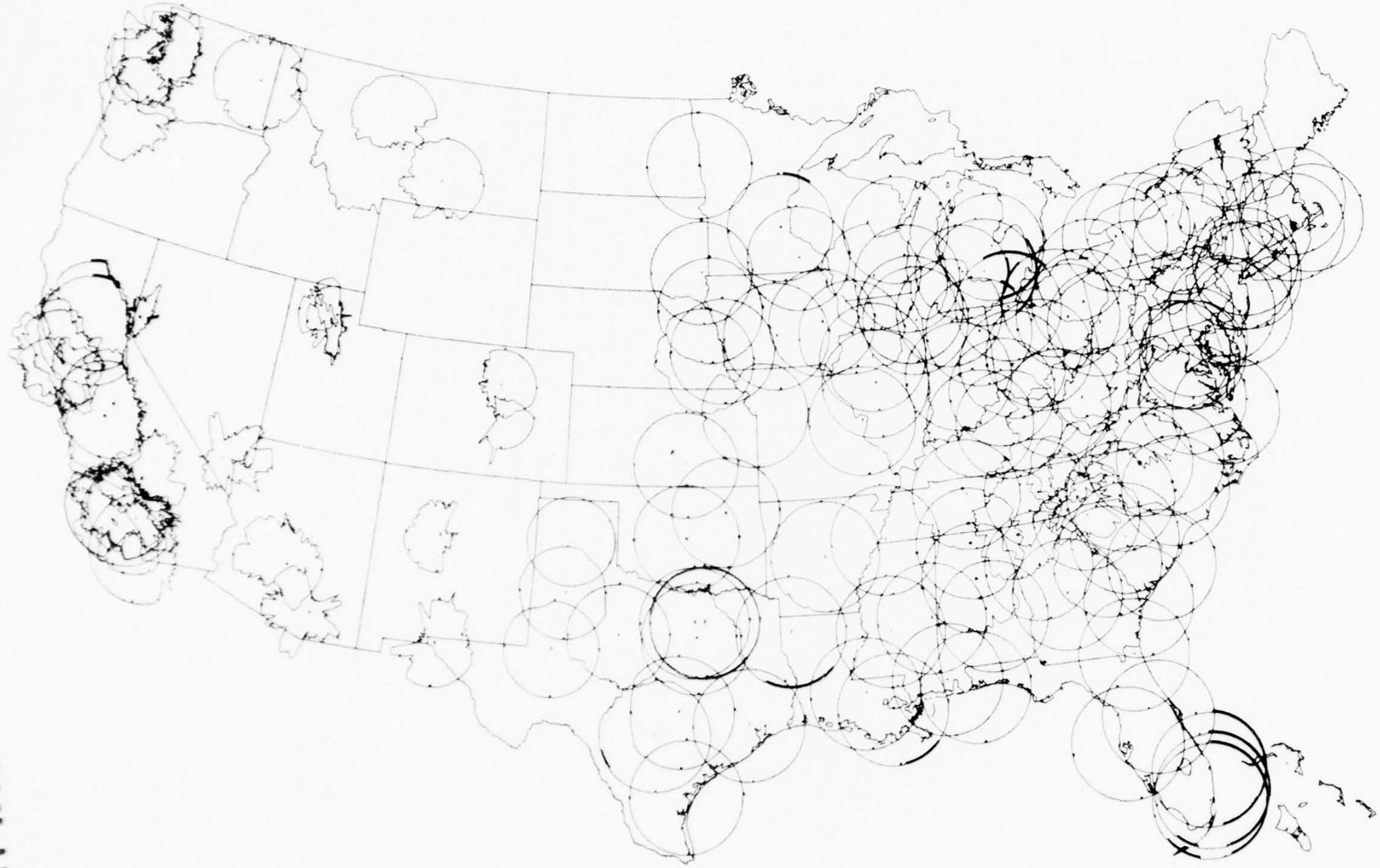

Fig. A.10. ASR composite coverage map, 10,000 ft. MSL, maximum range R_{max} = 100 nmi.

C44-1708

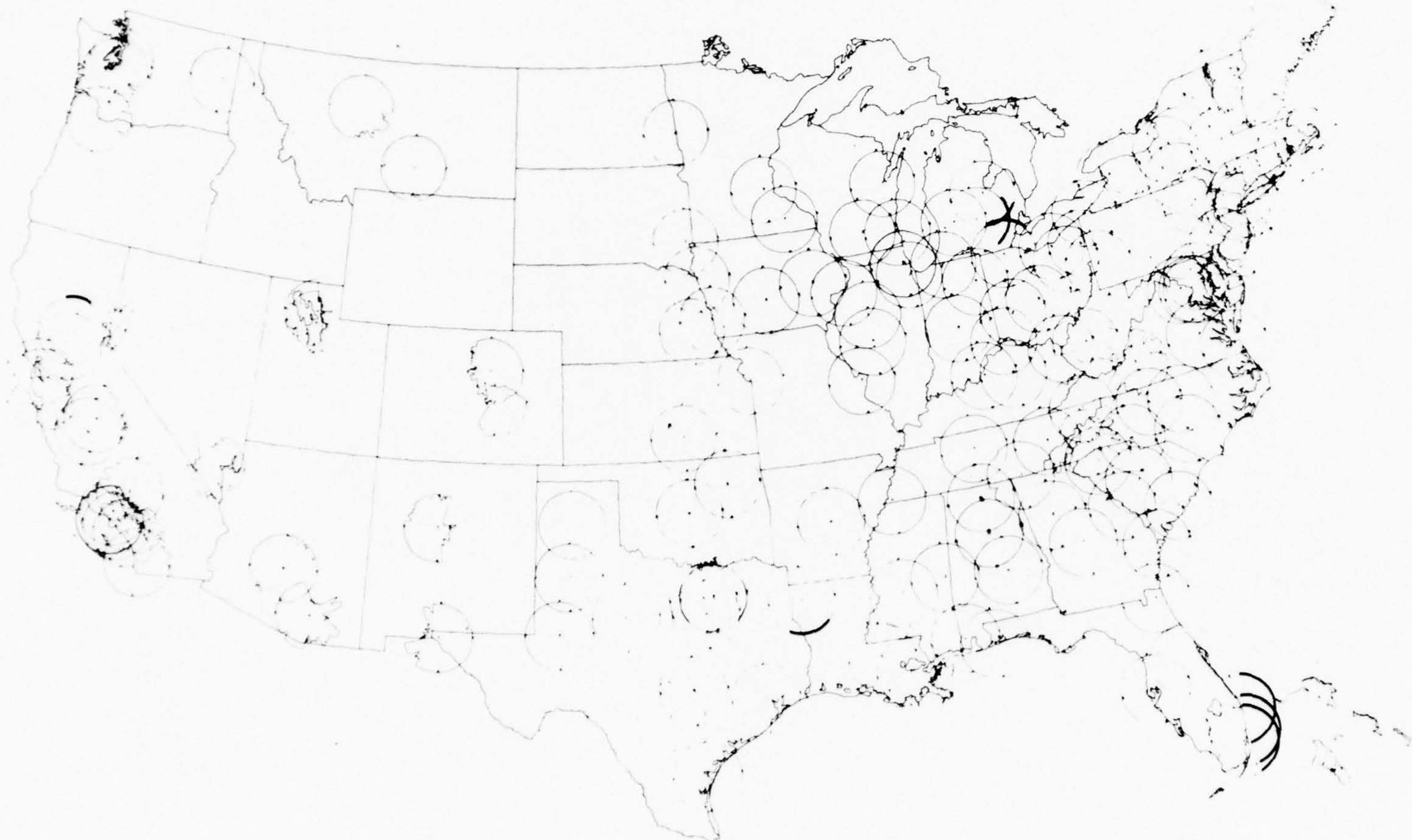

Fig. A.11. ASR composite coverage map, 10,000 ft. MSL, maximum range R_{max} = 60 nmi.

C44-1710

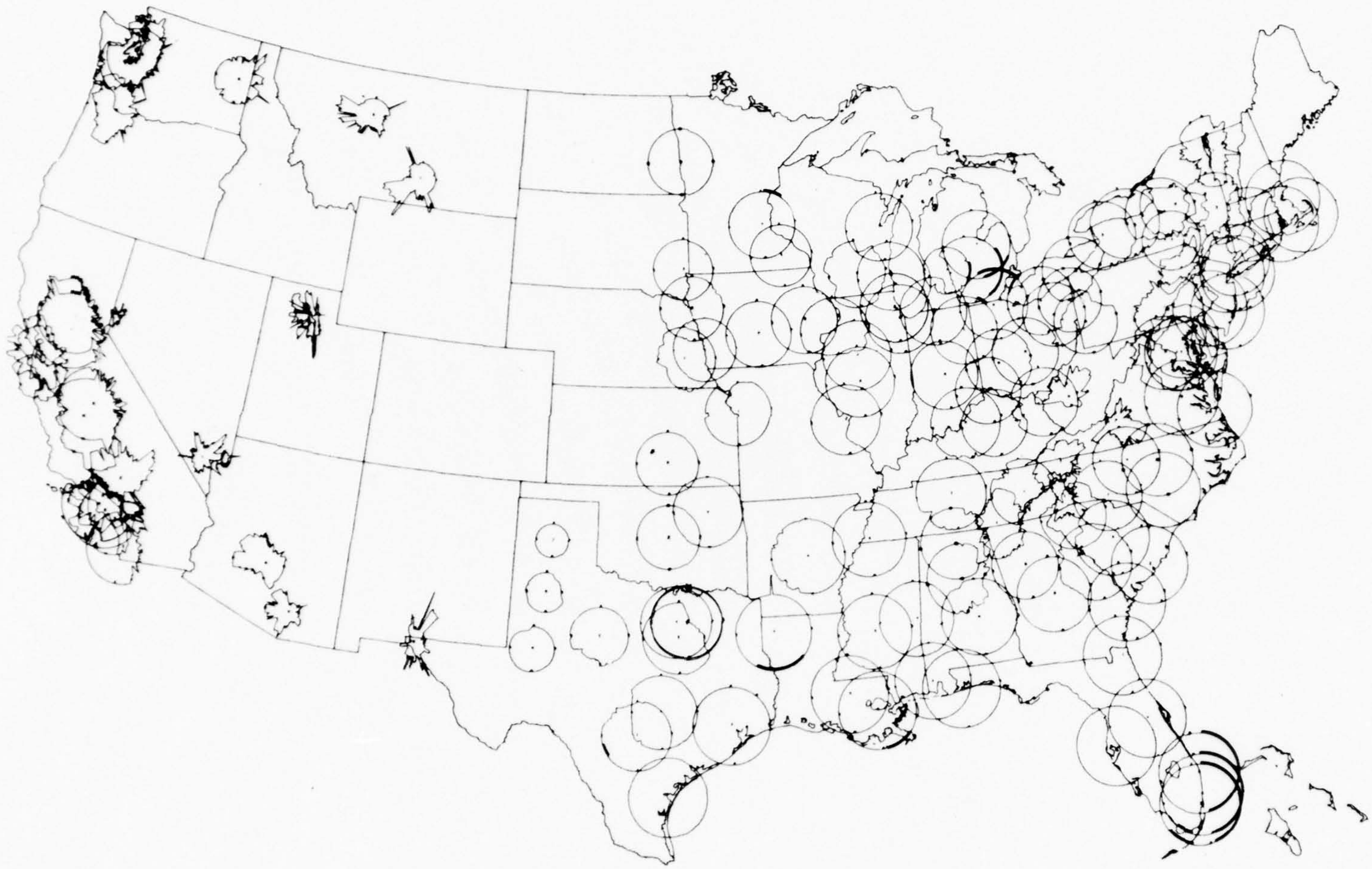

Fig. A.12. ASR composite coverage map, 5,000 ft. MSL, maximum range $R_{max} \geq 71$ nmi.

C44-1704

Fig. A.13. ASR composite coverage map, 5,000 ft. MSL, maximum range R_{max} = 60 nmi.

C44-1703

Fig. A.14. ASR composite coverage map, 3,000 ft. MSL, maximum range $R_{max} \geq 52$ nmi.

C44-1695

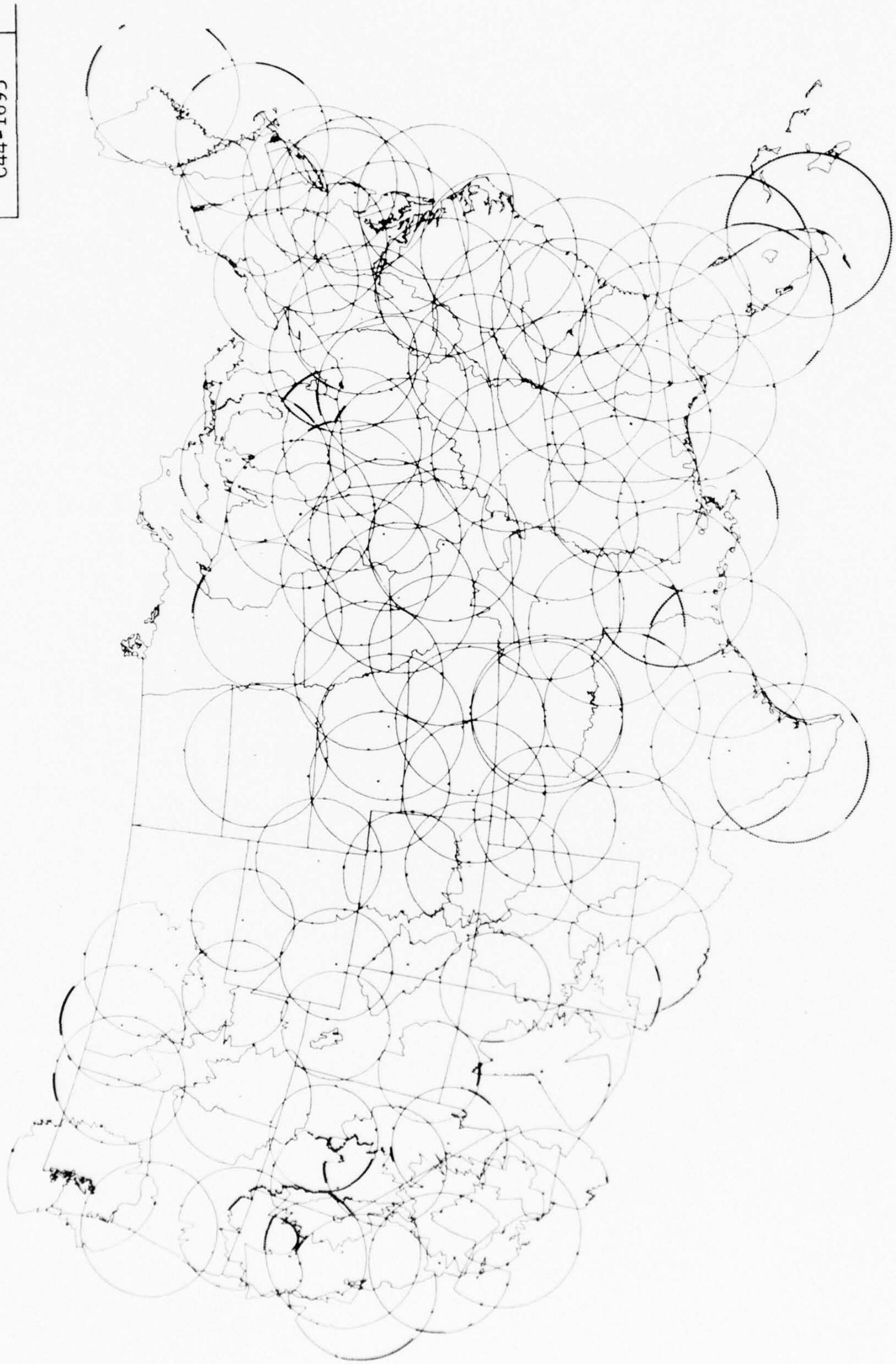

Fig. A.15. ARSR composite coverage map, 20,000 ft. MSL, maximum range $R_{max} \geq 156$ nmi.

Fig. A.16. ARSR composite coverage map, 20,000 ft. MSL, maximum range R_{max} = 150 nmi.

C44-1697

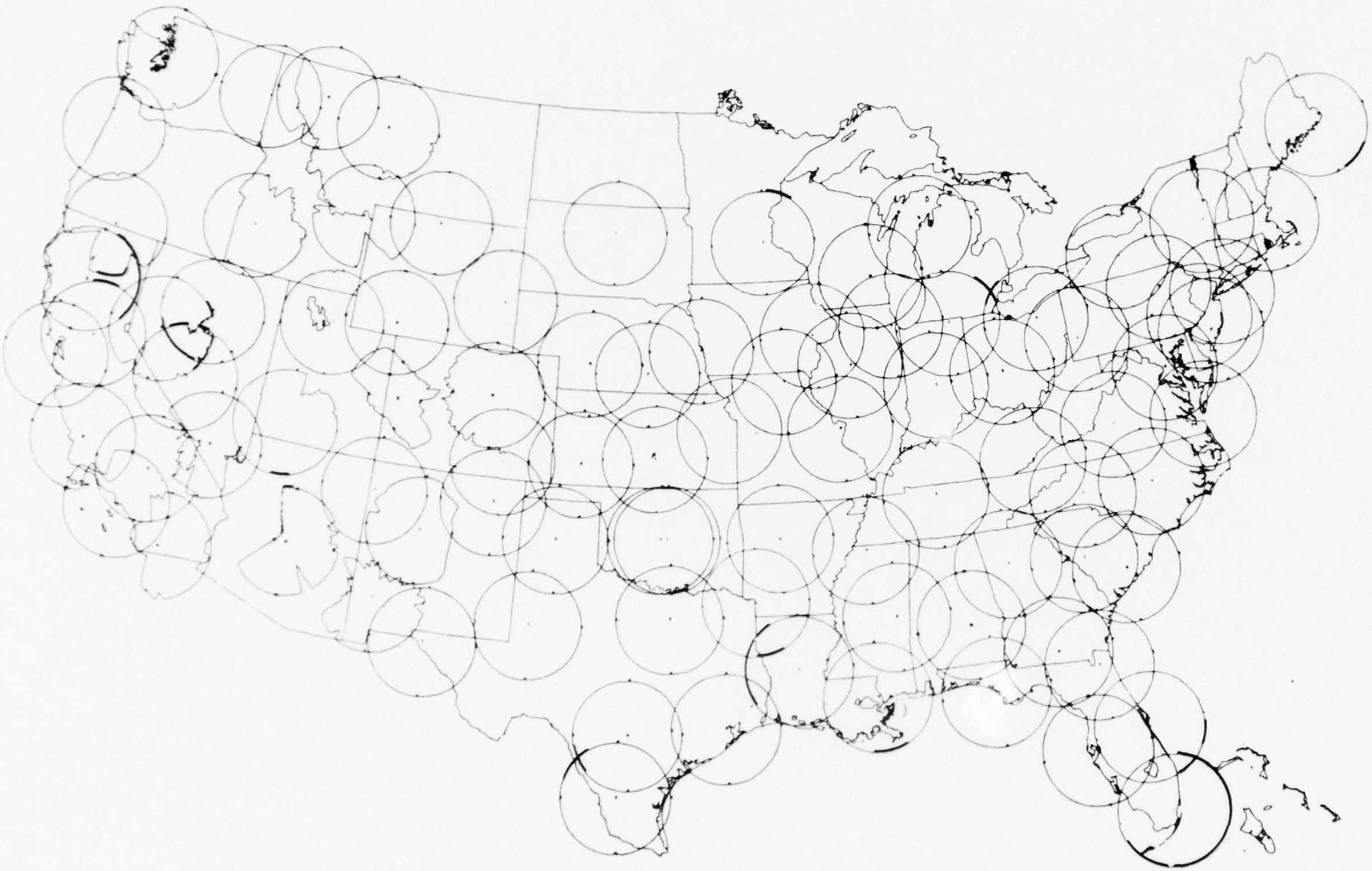

Fig. A.17. ARSR composite coverage map, 20,000 ft. MSL, maximum range R_{max} = 100 nmi.

C44-1692

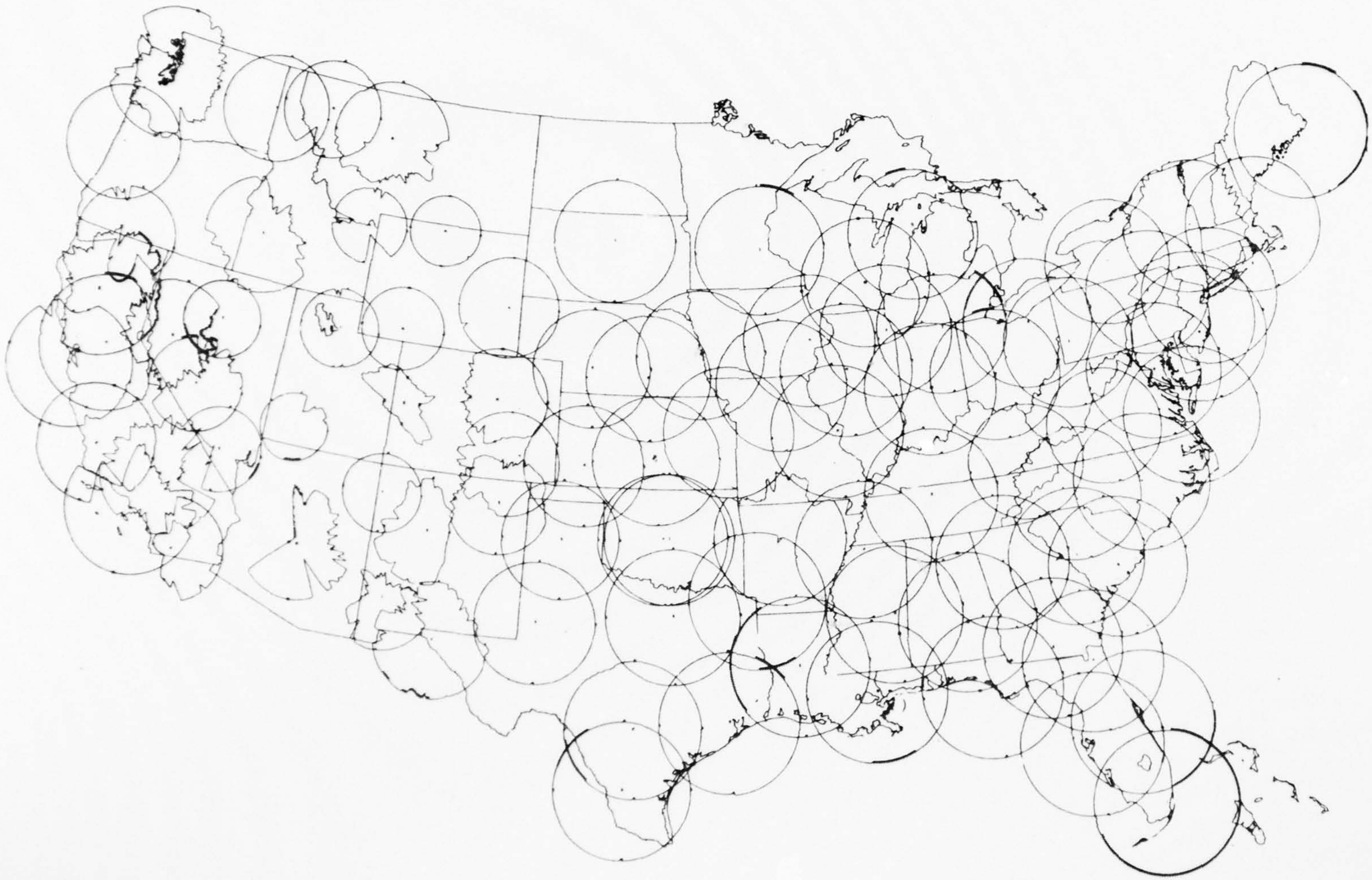

Fig. A.18. ARSR composite coverage map, 15,000 ft. MSL, maximum range $R_{max} \geq 133$ nmi.

C44-1698

Fig. A.19. ARSR composite coverage map, 15,000 ft. MSL, maximum range R_{max} = 100 nmi.

C44-1699

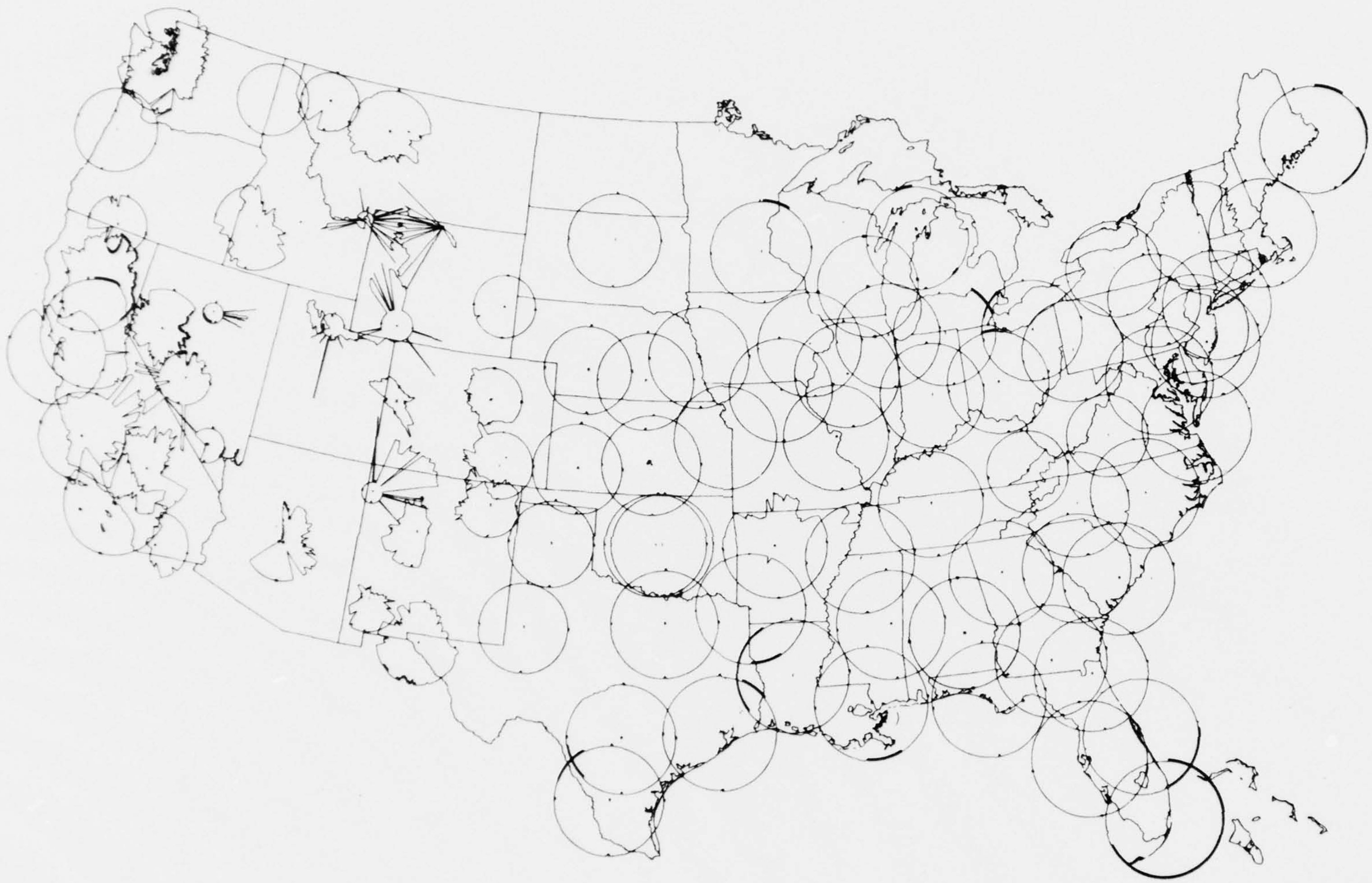

Fig. A.20. ARSR composite coverage map, 10,000 ft. MSL, maximum range $R_{max} \geq 106$ nmi.

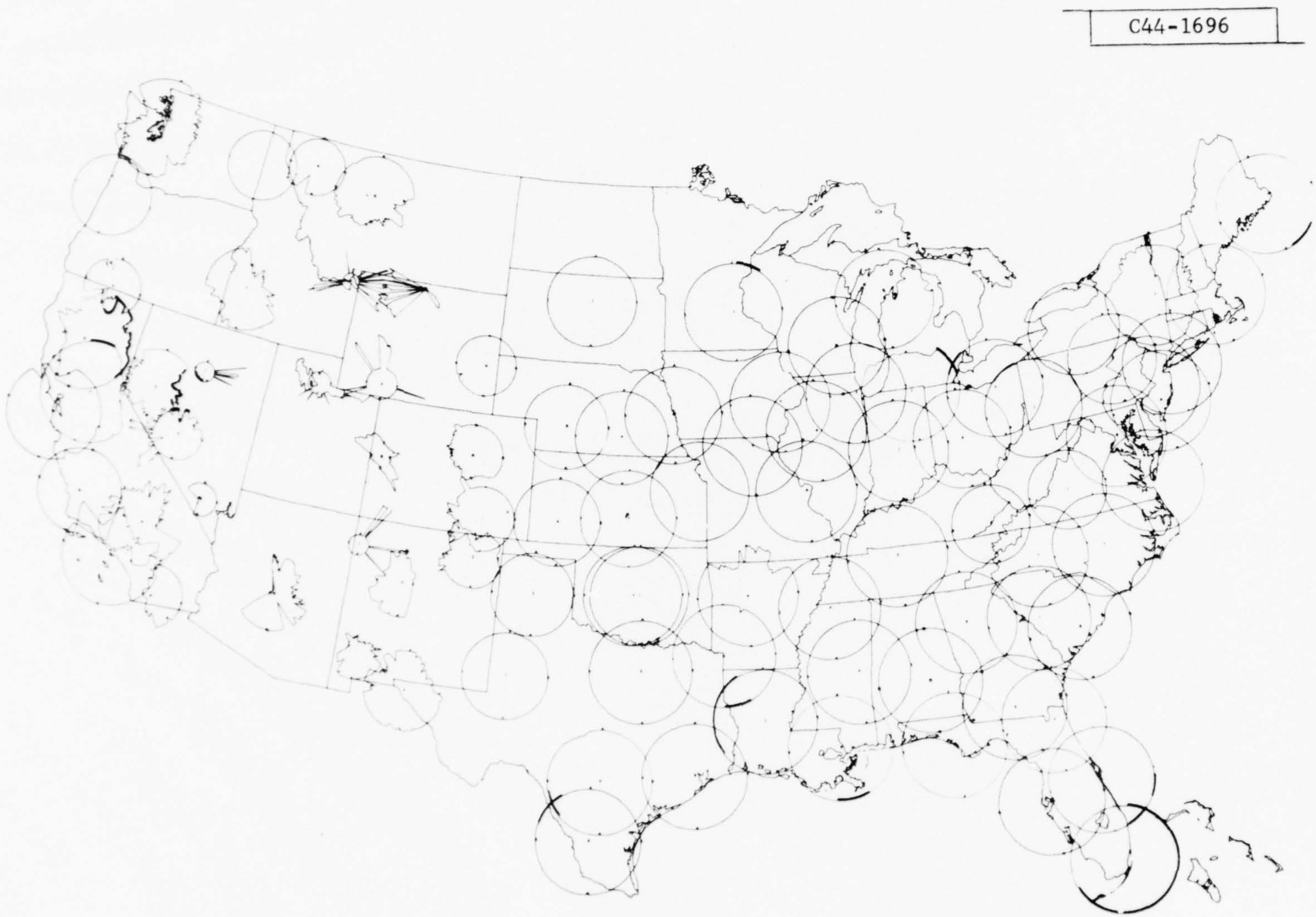

Fig. A.21. ARSR composite coverage map, 10,000 ft. MSL, maximum range R_{max} = 100 nmi.

C44-1700

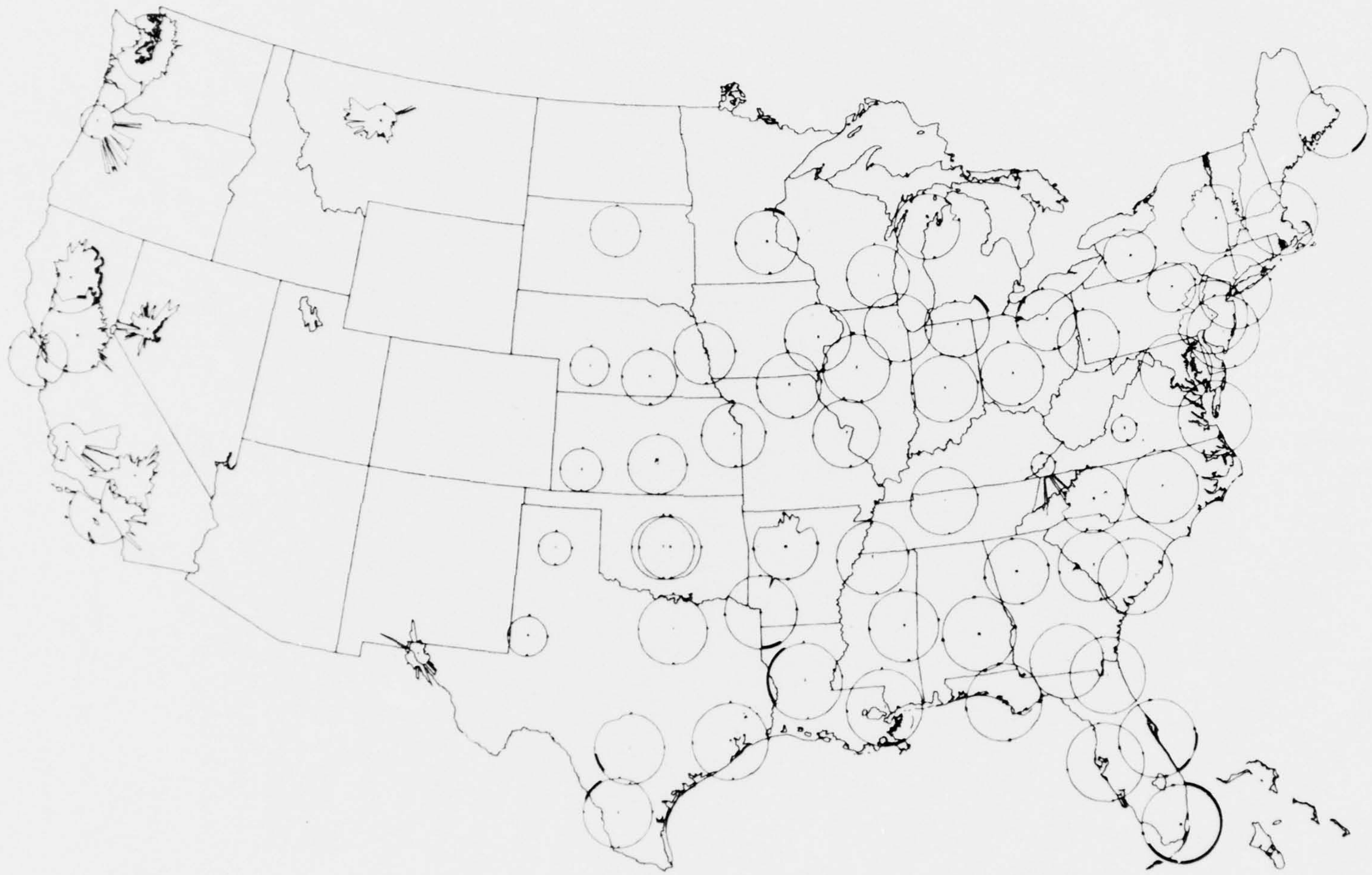

Fig. A.22. ARSR composite coverage map, 5,000 ft. MSL, maximum range $R_{max} \geq 71$ nmi.

C44-1679

Fig. A.23. Proposed ASR composite coverage map, 20,000 ft. MSL, maximum range R_{max} = 100 nmi.

C44-1681

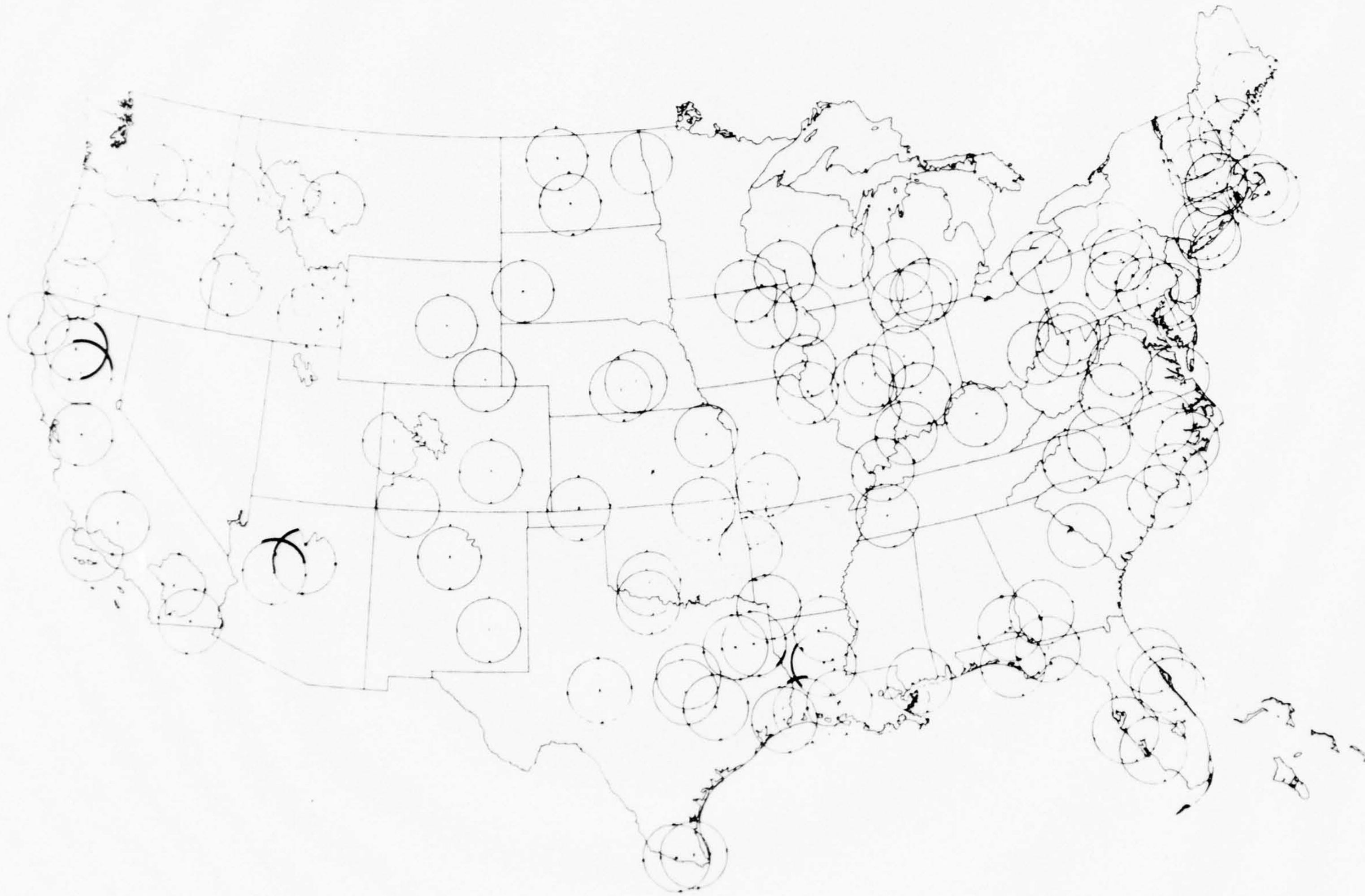

Fig. A.24. Proposed ASR composite coverage map, 20,000 ft. MSL, maximum range R_{max} = 60 nmi.

Fig. A.25. Proposed ASR composite coverage map, 15,000 ft. MSL, maximum range $R_{max} \geq 133$ nmi.

C44-1683

Fig. A.26. Proposed ASR composite coverage map, 15,000 ft. MSL, maximum range R_{max} = 100 nmi.

C44-1686

Fig. A.27. Proposed ASR composite coverage map, 15,000 ft. MSL, maximum range R_{max} = 60 nmi.

C44-1685

Fig. A.28. Proposed ASR composite coverage map, 10,000 ft. MSL, maximum range R_{max} = 100 nmi.

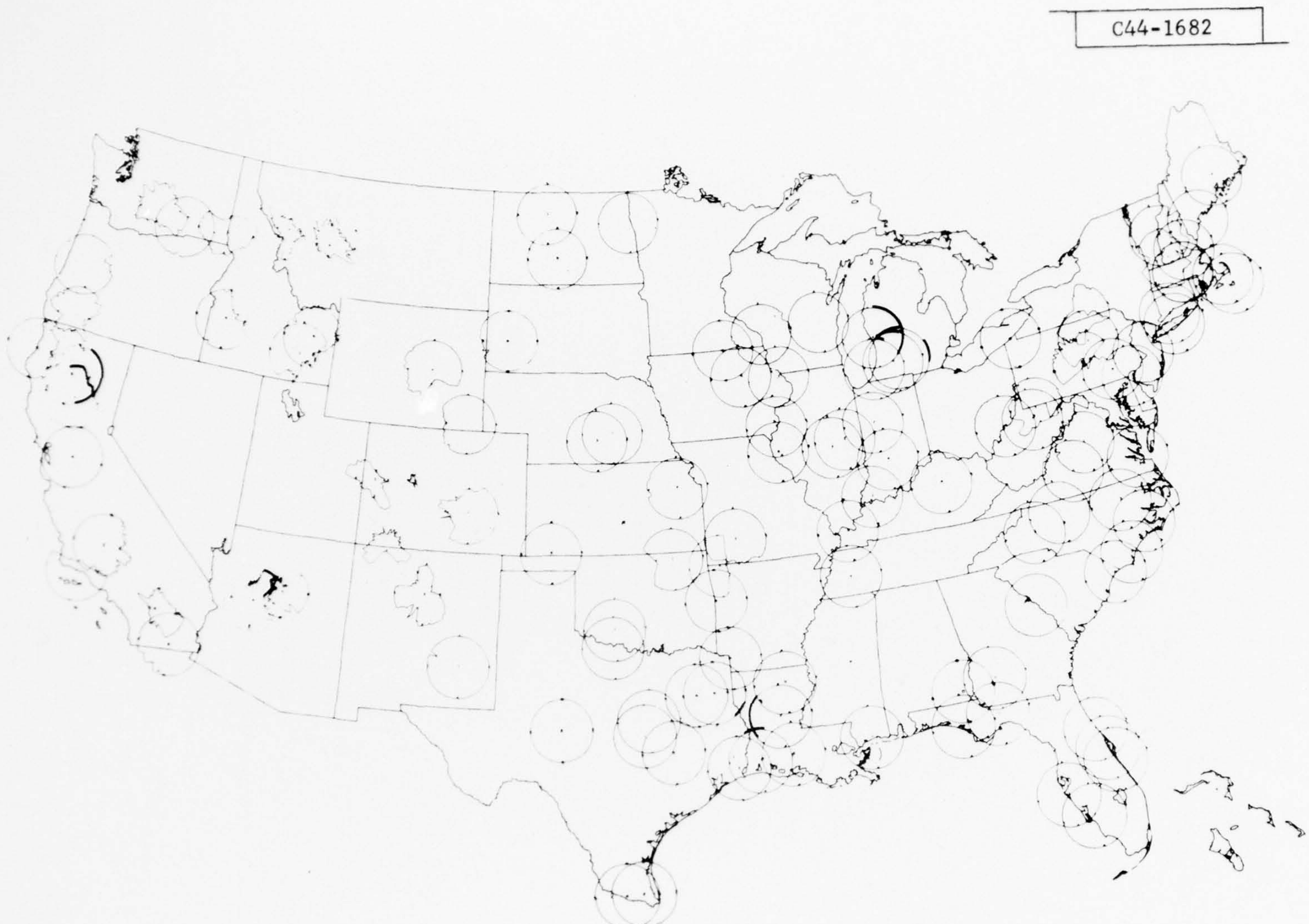

Fig. A.29. Proposed ASR composite coverage map, 10,000 ft. MSL, maximum range R_{max} = 60 nmi.

C44-1680

Fig. A.30. Proposed ASR composite coverage map, 5,000 ft. MSL, maximum range $R_{max} \geq 71$ nmi.

C44-1678

Fig. A.31. Proposed ASR composite coverage map, 5,000 ft. MSL, maximum range R_{max} = 60 nmi.

C44-1684

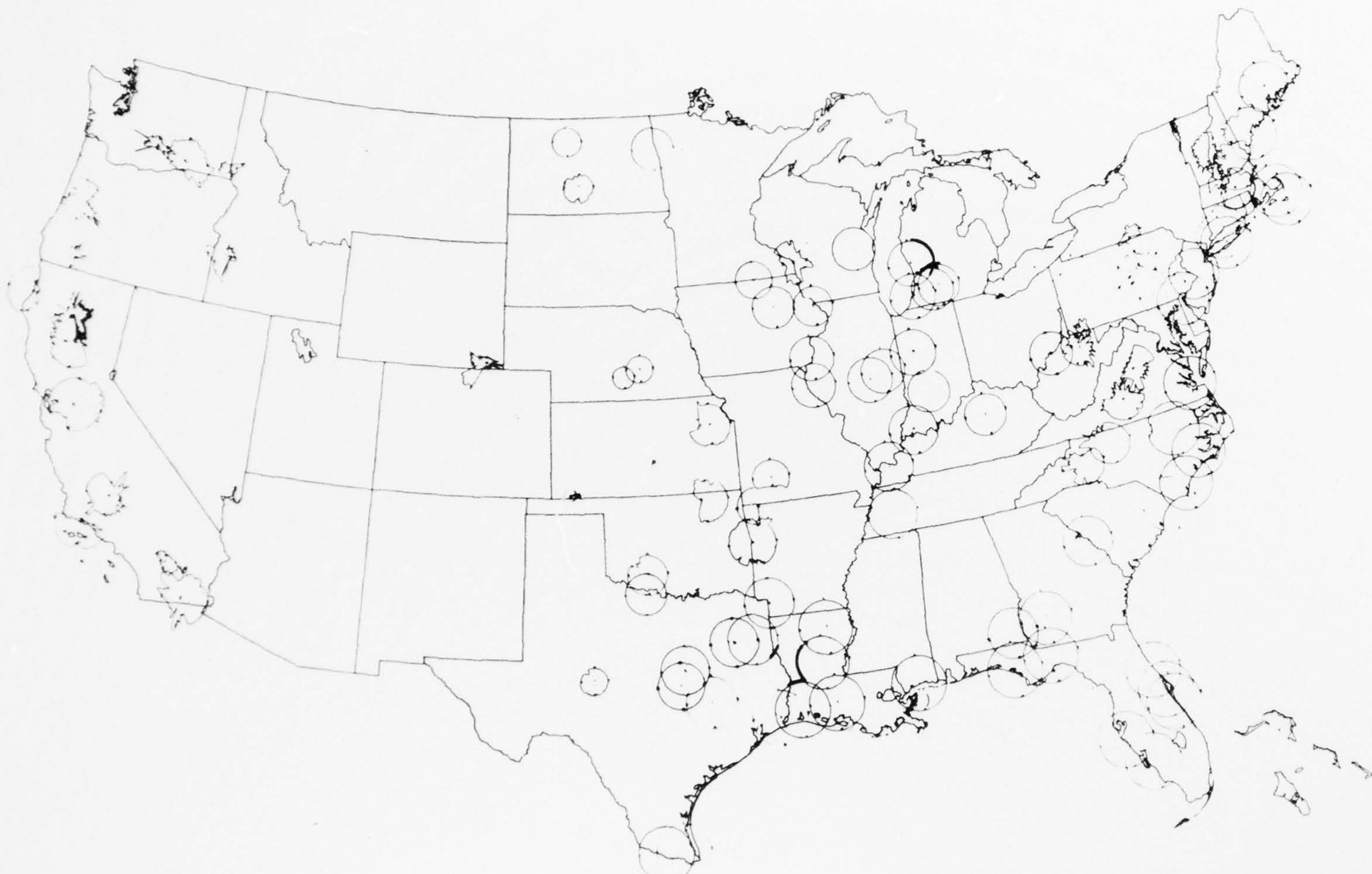

Fig. A.32. Proposed ASR composite coverage map, 3,000 ft. MSL, maximum range $R_{max} \geq 52$ nmi.

C44-1668

Fig. A.33. Proposed ARSR composite coverage map, 20,000 ft. MSL, maximum range $R_{max} \geq 156$ nmi.

C44-1675

Fig. A.34. Proposed ARSR composite coverage map, 20,000 ft. MSL, maximum range R_{max} = 150 nmi.

C44-1670

Fig. A.35. Proposed ARSR composite coverage map, 20,000 ft. MSL, maximum range R_{max} = 100 nmi.

C44-1669

Fig. A.36. Proposed ARSR composite coverage map, 15,000 ft. MSL, maximum range $R_{max} \geq 133$ nmi.

Fig. A.37. Proposed ARSR composite coverage map, 15,000 ft. MSL, maximum range R_{max} = 100 nmi.

C44-1674

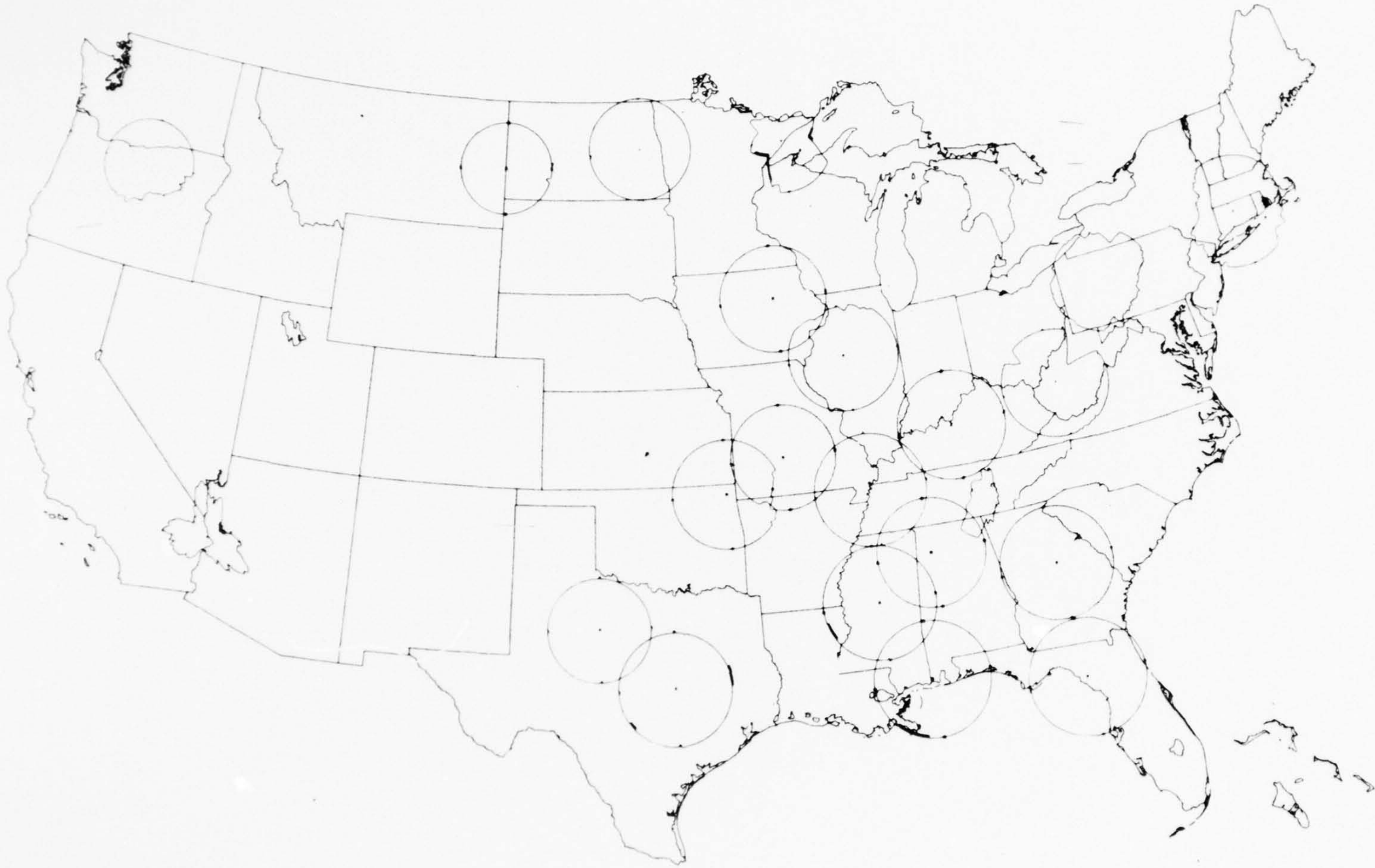

Fig. A.38. Proposed ARSR composite coverage map, 10,000 ft. MSL, maximum range $R_{max} \geq 106$ nmi.

C44-1671

Fig. A.39. Proposed ARSR composite coverage map, 10,000 ft. MSL, maximum range R_{max} = 100 nmi.

C44-1673

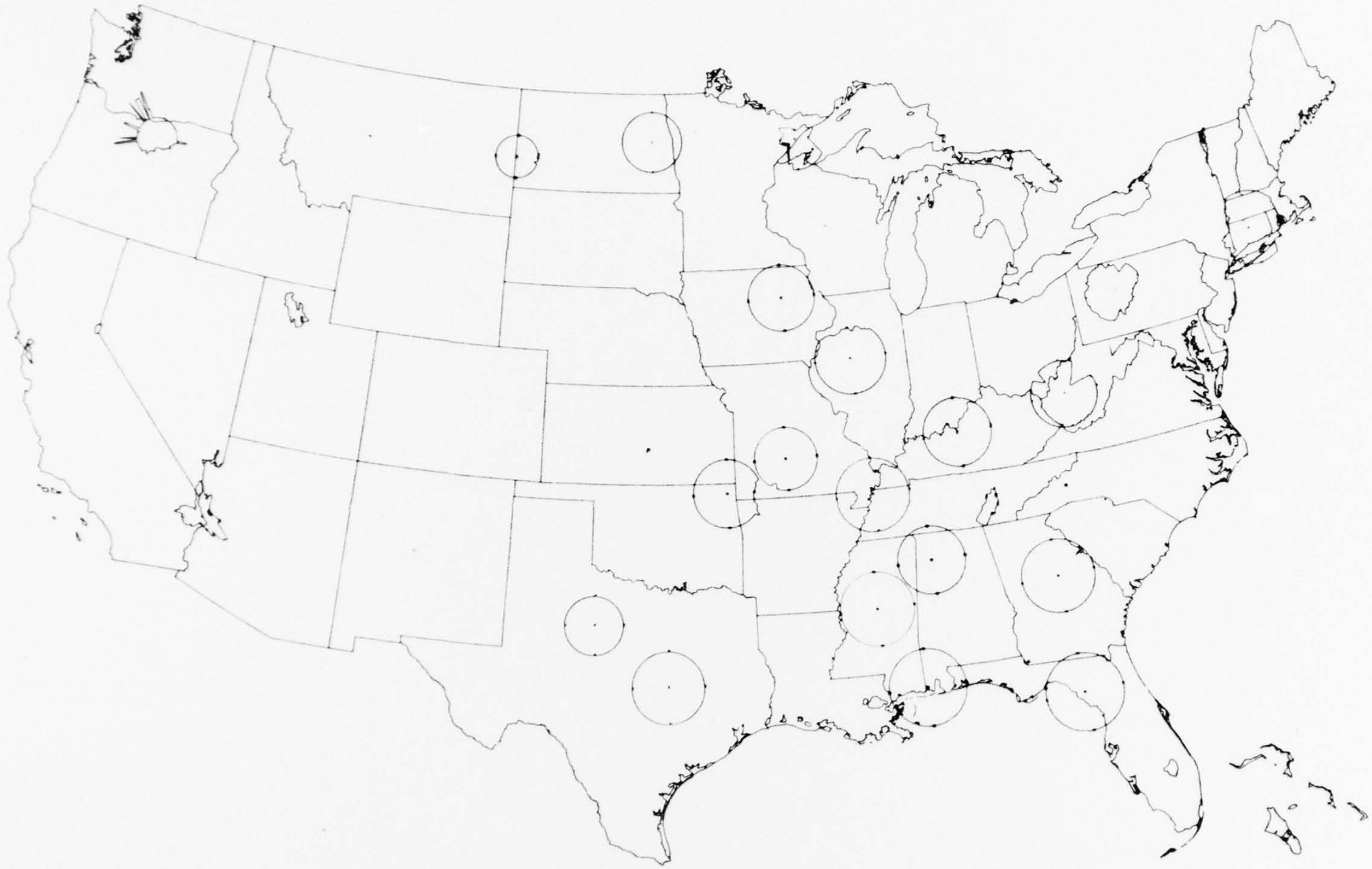

Fig. A.40. Proposed ARSR composite coverage map, 5,000 ft. MSL, maximum range $R_{max} \geq 71$ nmi.